SELECTION OF HEAT TOLERANT PARENTS AND THE DEVELOPMENT OF SUPERIOR HYBRIDS IN BOTTLE GOURD [*Lagenaria siceraria* (Mol.) Standl.]

A PhD DISSERTATION

BY

MD. SHAFIQUL ISLAM

Registration No: 1105072

DOCTOR OF PHILOSOPHY

IN

GENETICS AND PLANT BREEDING

DEPARTMENT OF GENETICS AND PLANT BREEDING

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY

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Dissertation submitted to the
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CERTIFICATION

This is to certify that the thesis entitled **"SELECTION OF HEAT TOLERANT PARENTS AND THE DEVELOPMENT OF SUPERIOR HYBRIDS IN BOTTLE GOURD [*Lagenaria siceraria* (Mol.) Standl.]"**, submitted by the examinee, bearing Registration No.: 1105072, Department of Genetics and Plant Breeding, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy (PhD) in Genetics and Plant Breeding, is a record of original research work carried out by him under my supervision.

To the best of my knowledge and belief, the work presented in this thesis is original and has not been submitted, either in part or in full, to any other university or institution for the award of any degree or diploma.

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DECLARATION

I hereby declare that the thesis entitled **"SELECTION OF HEAT TOLERANT PARENTS AND THE DEVELOPMENT OF SUPERIOR HYBRIDS IN BOTTLE GOURD [*Lagenaria siceraria* (Mol.) Standl.]"**, submitted to Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh, for the award of the degree of Doctor of Philosophy (PhD), is based on my own original research work carried out by me under proper supervision.

I also declare that this thesis, in whole or in part, has not been submitted to any other university or institution for the award of any degree or diploma. The work presented is entirely my own, and any information or material taken from other sources has been duly acknowledged.

The Author
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August 2026

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The Author

THIS HUMBLE EFFORT IS

DEDICATED TO

MY BELOVED MOTHER

&

AKLIMA, SARAH AND SOHA

ABBREVIATIONS AND SYMBOLS

Abbreviations/ Symbols	Meanings
AEZ	Agro Ecological Zone
ANOVA	Analysis of variance
AVRDC	Asian Vegetables Research and Development Centre
BAU	Bangladesh Agricultural University
GAU	Gazipur Agricultural University
BARI	Bangladesh Agricultural Research Institute
BBS	Bangladesh Bureau of Statistics
CD	Critical difference
CV	Coefficient of variation
d.f.	Degrees of freedom
et. al.	Et alu = Other people
FAO	Food and Agricultural Organization
HSTU	Hajee Mohammad Danesh Science and Technology University
i.e.	id est (That is)
σ^2A	Additive variance
σ^2D	Dominance variance
σ^2e	Error variance
σ^2g	Genotypic variance
σ^2p	Phenotypic variance
h^2b	Heritability in broad sense
h^2n	Heritability in narrow sense
Ha	Hectare
GA	Genetic advance
GCA	General combining ability
SCA	Specific Combining ability
Kg	Kilogram
LSD	Least significant difference
MP	Mid-parent
MS_E	Error mean square
MS	Mean Sum of Square
PCV	Phenotypic coefficient of variation
pH	Negative logarithm of hydrogen ion (H+) concentration
TSP	Triple super phosphate
RCB	Randomized complete block
RH	Relative Humidity
R&D	Research and Development
r_p	Phenotypic correlation
r_g	Genotypic correlation
SE	Standard error
Viz.	Namely

SELECTION OF HEAT TOLERANT PARENTS AND THE DEVELOPMENT OF SUPERIOR HYBRIDS IN BOTTLE GOURD [*Lagenaria siceraria* (Mol.) Standl.]

ABSTRACT

Rising summer temperatures in Bangladesh severely constrain bottle gourd productivity, necessitating the identification of heat-tolerant parents and the development of superior hybrids. To address this challenge, a comprehensive research program was conducted from 2022 to 2025 at the BRAC Vegetable Research Center, Dinajpur, involving fifty-eight (58) genetically diverse bottle gourd genotypes. The study aimed to assess genetic variability and screen heat-tolerant genotypes, identify superior parents through combining ability, and develop heterotic hybrids under heat stress. Initially, the 58 genotypes were evaluated under both optimum (Rabi) and heat-stress (Kharif) environments for morphological, yield-contributing, and quality traits. Wide and significant genetic variability was observed for days to first female flower appearance, node number at first female flower appearance, days to first edible fruit harvest, fruit length, fruit diameter, number of fruits per plant, fruit weight, fruit yield per plant, total soluble solids, dry matter content, and ascorbic acid content. High heritability coupled with high genetic advance for most traits indicated the predominance of additive gene action and substantial scope for genetic improvement through selection. Correlation and path analyses identified number of fruits per plant, fruit weight, and fruit diameter as primary yield determinants, with earliness contributing indirectly, establishing these traits as key selection criteria under heat stress. Heat tolerance was assessed using combined stress tolerance indices of major yield-contributing traits. Based on indices values, ranking, and cluster analysis, genotypes were classified into 21 heat-tolerant, 18 mid-tolerant, and 19 susceptible groups. From these, 20 tolerant and two mid-tolerant genotypes were selected for further evaluation through line × tester analysis under heat stress conditions. Combining ability analysis identified several parents with desirable general combining ability (GCA) effects for earliness, fruit size, yield components, and yield per plant. Based on per se performance and GCA ranking, six genotypes with BG-01, BG-16, and BG-21 as strong general combiners and BG-42, BG-55, and BG-53 as moderate but trait-specific good combiners were selected for a 6 × 6 full diallel mating design. Diallel analysis conducted during Kharif 2025 under heat stress showed highly significant GCA, SCA, and reciprocal effects for all studied traits, confirming the involvement of additive, dominance, and maternal genetic components, as well as the importance of cross direction in hybrid performance. Among the parents, BG-53 and BG-21 were identified as superior general combiners for fruit yield and major yield determinants. Heterosis analysis revealed significant positive heterosis over mid-parent, better-parent, and standard checks for yield and yield-contributing traits under heat stress. The hybrid BG-53 × BG-16 exhibited maximum heterosis for number of fruits per plant and fruit yield per plant. BG-53 × BG-01 recorded the highest heterosis for average fruit weight along with substantial yield advantage. BG-55 × BG-42 showed significant heterosis for fruit diameter along with favorable yield and quality traits. Crosses BG-01 × BG-21 and BG-21 × BG-53 combined desirable earliness with high yield heterosis, indicating strong dominance and over-dominance effects under heat-stress conditions. Genotypes BG-53 (mid-tolerant, early, and prolific) and BG-21 (tolerant, with higher fruit weight and yield) were identified as key parental lines for heat-stress breeding programs. The hybrids BG-53 × BG-16, BG-53 × BG-01, BG-01 × BG-21, BG-21 × BG-53, and BG-55 × BG-42 were selected as promising for potential commercial hybrid development under heat stress in Bangladesh.

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CHAPTER I
INTRODUCTION

Bottle gourd (*Lagenaria siceraria* (Mol.) Standl.) is a widely cultivated and economically important cucurbit vegetable in tropical and subtropical regions, valued for its nutritional importance, adaptability, and diverse culinary uses, belonging to the family Cucurbitaceae (2n = 22). It is one of the earliest domesticated cucurbits and is believed to have originated in Africa (Whitaker and Carter, 1961), although its dispersal pathways into Asia and the Americas are still debated (Gurcan *et al.*, 2015). Among the six known species in the genus Lagenaria, only *L. siceraria* is domesticated, and the remaining species are wild, perennial, and dioecious (Bose and Som, 1986).

Bottle gourd is an annual, monoecious, and predominantly cross-pollinated climber characterized by vigorous growth, extensive root systems, and solitary male and female flowers that bloom in the evening and last for only a single day (Achigan-Dako *et al.*, 2008; Tiwari and Ram, 2009). The fruits exhibit extraordinary variability in size, shape, and color, ranging from globular, cylindrical, bottle-shaped, or club-shaped to pale or dark green (Morimoto *et al.*, 2004; Singh, 2008). Bitterness in fruits, although uncommon in cultivated types, is genetically dominant and controlled by a single gene, cucurbitacins (Tyagi, 1976; Milind and Satbir, 2011).

The crop is highly valued for its diverse uses. The tender fruits are consumed as vegetables, and leaves and young stems serve as supplementary foods, while mature fruits are traditionally used as utensils and musical instruments (Akhond *et al.*, 2025; Srivastava *et al.*, 2014; Hart, 2011). It is a nutritionally and medicinally important vegetable. The fruits are rich in dietary fiber, essential minerals (iron, calcium, phosphorus, potassium, zinc, and magnesium), vitamins (A, B, C, and E), and amino acids (Milind and Satbir, 2011). Nutrient composition per 100 g edible portion includes 96.1 g water, 0.2 g protein, 0.1 g fat, 0.5 g minerals, 0.6 g fiber, 2.5 g carbohydrate, and 12 kcal of energy, in addition to 20 mg calcium, 10 mg phosphorus, and 0.7 mg iron (Kavitha *et al.*, 2006). Its high-water content (>90%) and easy digestibility make it especially valuable for dietary therapy, being widely recommended for weight management, hypertension, cardiovascular health, diabetes, hepatic disorders, ulcers, and digestive ailments (Ghule *et al.*, 2007; Sukhlecha, 2012). Bottle gourd seeds are an important source of edible oil, containing

proteins, essential amino acids, and fatty acids dominated by linoleic acid (Achu *et al.*, 2005; Ogunbusola *et al.*, 2010). These nutritional and medicinal properties have contributed to its recognition as a functional food crop of growing global importance.

In Bangladesh, bottle gourd was cultivated on 50,113 acres of land during 2023–24, producing 313,583 tons. Although the cultivated area has remained stable over the past three years, production has shown a steady increase (BBS, 2024). The crop is mainly grown in Dhaka, Chattogram, and Khulna divisions, while other regions like Mymensingh, Rajshahi, Barishal, Rangpur, and Sylhet contribute modestly. The major bottle gourd producing districts are Dhaka, Cumilla, Jashore, Jhalokati, and Mymensingh, which together contribute a substantial share of the national production (BBS, 2024; Islam, 2017). The national average yield is 6.26 tons/acre (BBS 2024), considerably lower than in other tropical countries. It is cultivated both in homesteads and commercial fields. It is traditionally known as the "poor man's vegetable" but has increasingly gained popularity among health-conscious urban consumers. The crop thrives under hot, humid conditions but grows optimally at day and night temperatures of 25–28 °C and 18–20 °C, respectively (Akhond *et al.*, 2025; Maurya *et al.*, 1993). With its expanding market demand and high profitability, bottle gourd is now cultivated nearly year-round in Bangladesh. Despite this, it remains an understudied and underutilized vegetable in national breeding and research programs.

Agriculture in Bangladesh, as in many tropical countries, is increasingly threatened by climate change. The global climate has changed steadily over the past century (Zhang *et al.*, 2019; Lesk *et al.*, 2016). Climate change, global warming, and increasing weather variability have emerged as major challenges to global agriculture and crop productivity (Shakoor *et al.*, 2011). Climate change is elevating global surface temperatures, inducing heat stress in plants and having a negative impact on their development, growth, and yield; resulting in the altering of rainfall patterns; and shortening winter seasons (Sultan *et al.*, 2019). Over the past century, the mean global temperature has increased by approximately 0.5°C, with projections suggesting an additional rise of 0.3°C per decade (IPCC, 2014). Estimates indicated that by 2025, global temperatures may increase by 1°C, and nearly 3°C by 2100, thereby intensifying the threat of global warming (Porter, 2005). Developing countries are expected to be disproportionately affected, as nearly 50% of their populations depend directly on agriculture, and approximately 75% of the world's poor reside in rural areas (Shakoor *et al.*, 2011; Porter, 2005). Rising temperatures have already

reduced crop yields, and with the global population projected to reach 9–10 billion by 2050 (Cole *et al.*, 2018; Waraich *et al.*, 2011), food demand will increase substantially (Waraich *et al.*, 2012; Sultan *et al.*, 2019; Sun *et al.*, 2019), thereby posing a serious threat to global food security.

Abiotic stresses, including heat, drought, and salinity, induce diverse morphological, physiological, biochemical, and molecular changes in plants, limiting growth and productivity (Ergin *et al.*, 2021). Among these, high temperature negatively impacts photosynthesis, growth, root and shoot development, flowering, and fruit setting, ultimately causing severe reductions in yield and quality (Szymanska *et al.*, 2017; Fahad *et al.*, 2017; Kim *et al.*, 2020). The average land temperature during 2006–2015 was 1.53°C higher than that of 1850–1900, which is 0.66°C greater than the corresponding global mean increase, with warming contributing to altered growing seasons and regional yield reductions (Shukla *et al.*, 2019). Crop models predict yield losses of 2.5–16% for every 1°C increase in seasonal temperatures, highlighting the vulnerability of tropical and subtropical crops (Lobell *et al.*, 2008; Haq *et al.*, 2019). The Intergovernmental Panel on Climate Change (IPCC Expert Meeting Report, 2007) projected that global mean temperatures will increase by approximately 0.2°C per decade, and at the end of the century, average temperatures may increase by 3°C or more, potentially altering crop distribution and the length as well as the altering of growing seasons (Porter, 2005). These projections highlight the urgent need for heat-tolerant technologies and breeding of heat-tolerant varieties to sustain crop productivity, as minimizing abiotic stress losses is essential for future food security and ensuring agricultural stress resilience (Camejo *et al.*, 2005; Mahajan and Tuteja, 2005; Zhou *et al.*, 2016).

In Bangladesh, average summer temperatures frequently reach 30–37°C and, during extreme events, exceed this threshold, leading to widespread crop damage and yield losses in various vegetable crops, especially bottle gourd (BBS, 2024). Alongside heat stress, plants are simultaneously exposed to other abiotic stresses such as irregular rainfall, drought, and humidity fluctuations, which in some cases persist throughout their life cycle under field conditions (Bita and Gerats, 2013). Cucurbits, though important in local diets, are especially vulnerable to temperature fluctuations. Moreover, photosynthesis is significantly inhibited at above-optimal temperatures, resulting in substantial reductions in potential crop productivity (Spaldon *et al.*, 2015; Saroj and Choudhary, 2020). It is

estimated that climate change may reduce cucurbit production by 15% globally (Olarewaju *et al.*, 2023). Bottle gourd, in particular, is highly sensitive to heat; temperatures above 30°C impair its physiological processes and fruit development, thereby lowering market quality and yield (Kumar and Reddy, 2021; Saroj and Choudhary, 2020). Given the increasing frequency of extreme heat episodes, breeding heat-tolerant genotypes is critical for sustaining production.

Genetic diversity provides the foundation for crop improvement. The knowledge of variability, heritability, and genetic advance is crucial for identifying superior parents and designing breeding strategies (Smith *et al.*, 1991; Zamir, 2001). Bottle gourd shows considerable genetic variation in fruit morphology, yield-contributing traits, physiological performance, and quality parameters (Sirohi and Sivakami, 1991; Sharma and Sengupta, 2012). Maintaining diversity within breeding pools is vital to sustain long-term improvement and avoid genetic uniformity. Greater genetic divergence between parents generally enhances heterosis in F_1s and broadens the scope for recombination (Arunachalam, 1991). Thus, a comprehensive assessment of genetic variability in bottle gourd is an important prerequisite for breeding progress.

Hybridization is one of the most effective approaches to crop improvement. Heterosis breeding, in particular, has played a major role in increasing yield, quality, and stress tolerance in cross-pollinated crops. Bottle gourd, being monoecious and highly cross-pollinated, is ideally suited for hybrid seed production, as high seed set makes F_1 hybrid development economical. Hybrids offer distinct advantages, including higher yield, earliness, quality, uniformity, and adaptability (Riggs, 1988). Considerable heterosis has been reported in bottle gourd (Tyagi, 1973; Singh, 2008), yet in Bangladesh hybrid adoption remains negligible due to limited breeding initiatives. Exploitation of heterosis involving locally adopted bottle gourd genotypes for commercial cultivation is a priority area of research for improving productivity, uniformity, and fruit quality. Identifying superior heterotic hybrids for yield, quality, and earliness, along with understanding the genetic basis of quantitative traits and parental prepotency, is essential for developing effective heterotic breeding strategies in bottle gourd. Therefore, there is good scope for improving the yield and other characteristics of bottle gourd through breeding.

Combining ability analysis (Sprague and Tatum, 1942) is a powerful tool for evaluating the genetic potential of parents and identifying superior hybrid combinations. General

combining ability (GCA) reflects additive gene effects and helps select promising parental lines, while specific combining ability (SCA) indicates non-additive effects important for exploiting heterosis. Such information is indispensable for designing effective breeding programs, particularly under stress conditions. In bottle gourd, combining ability studies enable breeders to identify superior parental lines for yield and yield-contributing traits, transfer desirable genes into progenies, and exploit heterosis more efficiently.

Despite its importance, heat tolerance in bottle gourd remains poorly studied. A few reports suggest the presence of genotypic variability for yield under heat and drought stress (Samadia, 2002; Rakesh and Ram, 2007; Husna *et al.*, 2011; Mashilo *et al.*, 2017), but genetic variability specific to heat tolerance is not well documented. Yield performance under both stressed and non-stressed conditions is considered a reliable indicator of heat tolerance (Blum, 1988). Heat stress indices such as stress tolerance index (STI), stress susceptibility index (SSI), and geometric mean yield are widely used to identify genotypes combining yield potential with stability across environments (Ehlers and Hall, 1998; Pour-Aboughadareh *et al.*, 2019). However, systematic breeding of heat-tolerant bottle gourd hybrids for summer cultivation in Bangladesh has not yet been pursued.

Considering the nutritional, economic, and cultural importance of bottle gourd, its vulnerability to heat stress, and the lack of targeted breeding programs, there is an urgent need to identify and develop heat-tolerant hybrids. Such hybrids would help sustain productivity, ensure vegetable availability year-round, and strengthen food security under the challenges of global warming. In light of these considerations, the present study was undertaken with the following specific objectives:

1. To assess genetic variability and trait relationships to identify selection criteria for yield improvement
2. To screen bottle gourd genotypes for heat tolerance using stress tolerance indices under optimum and heat-stress conditions
3. To select superior parents with high performance and combining ability for yield and related traits.
4. To estimate heterosis and selection of promising heat-tolerant heterotic F_1 hybrids for yield and related traits under heat stress

CHAPTER II

REVIEW OF LITERATURE

Bottle gourd [*Lagenaria siceraria* (Molina) Standl.] is one of the most economically important vegetable crops in Bangladesh as well as the Indian subcontinent. It belongs to the family Cucurbitaceae and the genus Lagenaria. A total of six species have been identified in the genus *Lagenaria*, but only *L. siceraria* is domesticated; the others are wild, perennial, and dioecious, whereas bottle gourd is annual, monoecious, and predominantly cross-pollinated (Bose and Som, 1986). National statistics indicate that the crop occupies approximately 50,112.96 acres of cultivated land, contributing a total annual production of about 313,586 metric tonnes, with an average yield of 6.26 MT per acre. Despite its economic significance, productivity remains lower than the potential yield reported in improved varieties, largely due to environmental stresses, including recurrent heat waves during the reproductive phase, which severely limit fruit set and final yield. Enhancing heat tolerance therefore remains a crucial breeding objective to stabilize and improve bottle gourd productivity under Bangladesh's increasingly warm climatic conditions. The main goal of most of the plant breeding programs is to increase the yielding ability of crop plants. Information on various quantitative and qualitative traits, particularly those that contribute to yield, will be most useful in planning and successful implementation of the breeding program. Hybridization, one of the means of obtaining increased yield and exploitation of heterosis, is proving an efficient approach for improvement of vegetable crops, and several researchers work on the crop improvement aspects of bottle gourd, especially on heterosis breeding in relation to better yield, on which the present investigation is carried out. Therefore, the literature on genetic variability, stress tolerance indices, and their role for thermotolerance, cross compatibility, combining ability, and heterosis in relation to parental divergence studied in bottle gourd under optimum and stress tolerance and other relevant crops under the family Cucurbitaceae have been reviewed and presented under the following headings:

2.1 Genetic Variability, Heritability and Genetic Advance in Bottle gourd

Bashir *et al.* (2024) evaluated seventy-seven (77) bottle gourds during the Kharif-II summer season and observed a considerable amount of variation for major yield traits. They demonstrated that fruit weight ranged from 0.79 to 4.40 kg with a mean of 1.92 kg, the number of fruits per plant from 3.4 to 8.6 with a mean of 4.53, and fruit yield per

hectare from 211.83 to 1132.21 quintals with a mean of 430.78 q. They recorded high values of PCV, GCV, heritability, and genetic advance for fruit weight, number of fruits per plant, fruit yield per plant, and fruit yield per hectare, suggesting a predominance of additive gene effects and effectiveness of direct selection. They concluded that the studied genotypes had wide genetic variability for yield, seed attributes, and quality traits, indicating high scope for improvement through selection.

Singh *et al.* (2024) evaluated genetic variability, heritability, and genetic advance in 100 bottle gourds (10 parents, 45 F_1s, and 45 F_2s) across sixteen traits, revealing highly significant variation for most reproductive and yield attributes. Phenotypic coefficients of variation consistently exceeded genotypic values, underscoring strong environmental influence, yet several traits displayed substantial genetic variability. The morphological traits ranged for dry matter content 4.18 to 5.95 with mean 5.01%, fruit length 23.52 to 51.51 cm with mean 42.88 cm, days to first fruit harvest 54.68 to 64.69 with mean 60.16, number of fruits per plant 3.03 to 8.21 with mean 4.98, fruit weight 0.66 to 1.37 kg with mean 1.00 kg. The key yield contributors, such as number of fruits per plant (GCV 3.22, PCV 64.6% in F_1), average fruit weight (GCV 0.43, PCV 42.8%), and fruit yield per plant (GCV 2.04, PCV 41.3%), also displayed substantial variability, indicating strong inherent differences among genotypes. Heritability was remarkably high for the pistillate:staminate ratio (98% in F_1; 97.7% in F_2), fruits per plant (96-96.8%), average fruit weight (~95%), fruit length (~91-95%), and total fruit yield (~94%), and these traits also expressed high genetic advance (up to 50-57% of the mean), suggesting predominance of additive gene action. The findings emphasized that reproductive ratio, fruit number, fruit weight, and yield were the most promising traits for genetic improvement in bottle gourd.

Duhan *et al.* (2022) studied 37 bottle gourd genotypes during the spring-summer (2017-18) season and reported wide genetic variability for all quantitative traits. A wide range of variations was observed in days to female flowering (48.67-65.00), days to first fruit harvest (57.33-77.00), number of fruits per vine (4.4-11.1), fruit yield (172.5-358.5 q/ha), fruit length (24.2-36.8 cm), and average fruit weight (530-1100 g). High GCV and PCV were recorded for vine length (18.90, 18.96%), fruits per vine (17.90, 18.37%), primary branches (16.36, 16.49%), and fruit yield (15.94, 16.01%), indicating strong genetic variability. Heritability was estimated very high (98%) for fruit length and primary branches, while diameter of fruit (72%) and crop maturity (68%) showed comparatively lower values. High genetic advance was also reported for vine length (38.80%), fruits per

vine (35.90%), primary branches (33.43%), yield (32.70%), and fruit length (20.30%), indicated good potential for direct selection in bottle gourd improvement programs.

Pandey *et al.* (2021) assessed 16 bottle gourd genotypes with 15 traits and recorded significant variability for all studied characters. The mean value for the node number at which the first female flower appeared was 10 to 20.63; days to first fruit harvest ranged from 54.70 to 71.77; fruit length was 22.86 cm to 43.80 cm; and fruit diameter was 6.63 cm to 10 cm. A range of heritability was also estimated from 4.11% to 36.25% for the studied traits. They recorded high variability in the number of primary branches per plant (PCV 36.25, 30.70) and node at first female flower (PCV 21.15%, GCV 20.17%) and moderate variability for fruit length (PCV 18.89%, GCV 18.44%), whereas days to first male flower anthesis (PCV 4.11%, GCV 3.42%) showed lower variation. The estimated heritability ranged from 4.11% to 36.25%, with the highest values for number of primary branches (36.25%) and node at first female flower (21.15%), coupled with higher genetic advance in primary branches (53.56%), fruit length (37.07%), and days to first female flower (17.66%), suggesting additive gene action presence in the studied genotypes.

Venkatraman and Haripriya (2021) evaluated 35 bottle gourd genotypes during the Jan-March 2020 season at Annamalai University, Tamil Nadu, India, and reported significant variations for all quantitative traits. A wider range of variation was observed for vine length (202.33-401.12 cm), fruit length (33.46-43.03 cm), fruit weight (1.40-2.38 kg), and yield per vine (11.98-22.35 kg). Moderate variability was observed for vine length (PCV 14.28%; GCV 13.78%) and primary branches (PCV 16.10%; GCV 13.43%). The study also estimated high heritability coupled with high genetic advance for key yield traits such as fruit length (h^2 = 0.87; GA = 11.46%), fruit width (h^2 = 0.76; GA = 11.73%), fruit weight (h^2 = 0.35; GA = 16.21%), fruits per vine (h^2 = 0.59; GA = 24.55%), and yield per vine (h^2 = 0.44; GA = 17.44%), indicated additive gene action and suggesting selection would be effective for genetic improvement.

Kumar *et al.* (2020a) investiagted 31 bottle gourd genotypes during the summer season of 2019 at SVPUAT, Meerut (U.P.), to evaluate the genetic variability and reported significant variations for all growth and yield traits. They recorded wide variation with maximum values for vine length (354.93 cm), fruit length (35.40 cm), fruit girth (33.80 cm), number of fruits per plant (11.53), fruit yield per plant (20.14 kg), and crop duration (132.40 days). High GCV and PCV were observed for fruit yield (36.23%, 38.42%),

primary branches (28.21%, 29.73%), and internode length (25.39%, 26.53%), indicating strong variability of the studied genotypes. Most traits showed high heritability, for traits such as fruit yield (GA% = 70.38), primary branches (55.13), and nodes per plant (51.42) exhibited high genetic advance.

Ghorpade *et al.* (2019) evaluated 21 bottle gourd genotypes during Kharif 2018 at Latur, India, and exhibited significant variability for four qualitative traits. The mean values varied widely, with ascorbic acid ranging from 5.17 to 7.92 mg, carbohydrate from 0.32 to 0.67%, protein from 1.13 to 2.95%, and TSS from 1.12 to 3.74%. High PCV and GCV were reported for carbohydrate content (PCV 21.88%, GCV 19.26%), protein (22.55%, 20.11%), and TSS (25.76%, 24.57%), indicated wider genetic variability and scope for selection, while ascorbic acid showed moderate variation (PCV 13.83%, GCV 13.05%). All traits exhibited high heritability (77.50-94.50%) coupled with high genetic advance, particularly for TSS (49.19%), protein (36.96%), carbohydrate (24.95%), and ascorbic acid (25.36%), suggesting a predominance of additive gene action and effectiveness of direct selection for quality improvement in bottle gourd.

Iqbal *et al.* (2019) assessed nine exotic bottle gourd genotypes along with the local checks 'Louki' during the Kharif seasons of 2013 and 2014 and reported a wide range of variation in yield and quality traits. Among the assessed genotypes, fruit length ranged from 31.1 to 52.8 cm, fruit width from 11.5 to 17.1 cm, fruit weight from roughly 920 g to 1330 g, fruits per plant from 4.5 to 25.4, and fruit yield varied from 20.2 to 50.1 t/ha. The local variety, Louki, had a mean yield of about 20.7 t/ha, with shorter fruits (approx. 32 cm), lighter fruits (approx. 923 g), and only about 5-6 fruits/plant, whereas the exotic genotype 'Anmol' was clearly superior, giving an average of approx. 24-25 fruits/plant, longer fruits (approx. 52 cm), heavier fruits (approx. 1.3 kg), and the highest mean yield (49 t/ha). For the quality features also exhibited, the range of variations of total soluble solids (TSS) varied from 3.6 to 7.1 °Brix and ascorbic acid (vitamin C) from 13.2 to 16.1 mg/100 g; 'Anmol' combined high yield with relatively high TSS (≈7 °Brix) and vitamin C (16.1 mg/100 g), while Louki had lower yield but similar TSS (7.1 °Brix) and vitamin C (14.8 mg/100 g). The authors concluded that the exotic genotype Anmol was a promising, high-yielding, and good quality cultivar suited for cultivation under the agro-climatic conditions.

Sultana *et al.* (2018) evaluated 39 bottle gourd genotypes at the Lalteer Seed R&D farm at Gazipur (2016-2017) during the Rabi season to study the genetic variability, heritability, and genetic advance. Among the studied genotypes, different traits varied widely: for days to first male, the mean was 45.15 days (39.53-49.47); 53.27 days to first female flower (45.80-59.67); and 68.39 days to first harvest (60.63-74.67); plants had 24.09 branches/plant (18.47-31.70) and 5.13 fruits per plant (3.40-8.13). Mean fruit weight was 1.61 kg (1.26-1.92 kg), with fruit length 30.81 cm (14.33-49.25), fruit girth 11.57 cm (8.25-16.37), 100-seed weight 21.97 g (16.32-29.22), and yield 27.43 t/ha (17.47-39.76 t/ha). The highest GCV and PCV were for fruit length (35.6%), and heritability was very high (approx. 96-100%) with high genetic advance for fruit length (GAM 73.34%), yield (43.54%), fruits/plant (42.18%), and fruit girth (38.73%). They concluded this strong additive gene action might be good scope for parent selection.

Rambabu *et al.* (2017) examined 21 bottle gourd genotypes and showed wide genetic variability with high heritability. Among the studied genotypes, vine length varied from 3.26 to 9.98 m (GCV 30.26%, h^2 96%), and the number of fruits per plant from 3.92 to 8.09 (GCV 22.39%, h^2 93%), while fruit length ranged from 13.71 to 56.50 cm (GCV 38.07%, h^2 89%) and fruit width from 6.80 to 23.27 cm (GCV 37.11%, h^2 96%). Fruit yield per plant recorded high variability (3.20-9.67 kg) with GCV 25.50%, PCV 26.00%, h^2 96%, and genetic advance 51.51%, indicating strong additive gene effects. Quality traits like 100-seed weight (10.71-19.73 g, h^2 98%) and TSS (2.60-4.20 °Brix, h^2 86%) also showed high heritability. The estimated PCV was higher than GCV for most of the traits, indicating that environmental influence was low.

Singh *et al.* (2017) evaluated nine bottle gourd genotypes across three seasons (early winter, early summer, and summer) to assessed variability for yield-associated traits. The results showed highly significant genotypic differences for all assessed characters, indicating the presence of substantial genetic diversity. The earliest genotype for days to first fruit harvest was Pusa Naveen in all seasons, viz., 55.67 days in E1, 62.90 days in E3, and 109.20 days in E2 as a pooled value. The average fruit weight ranged between 0.76-1.35 kg, 0.94-1.41 kg, 0.99-1.55 kg, and 0.90-1.44 kg in E1, E2, and E3, respectively, with the minimum average fruit weight produced by genotype Pusa Naveen and the maximum average fruit produced by genotype HZP-RC-1. The key earliness trait, node number to first pistillate flower, exhibited moderate to high variability (PCV: 13.81-18.25%; GCV: 12.00-15.50%) and high heritability (72-87%) coupled with high genetic advance (up to

27.14%), suggesting predominance of additive gene action and scope for effective selection. Among yield components, the number of fruits per vine recorded PCV 18.54-21.85%, GCV 14.95-16.63%, heritability 51-80%, and genetic advance 23.11-30.72%, while average fruit weight exhibited PCV 13.64-19.69%, GCV 12.45-17.80%, heritability 78-89%, and genetic advance 23.40-33.17%. Fruit yield per vine also showed moderate genetic variability (PCV 12.44-18.45%; GCV 9.00-14.56%) with heritability of 52-62% and genetic advance of 13.40-23.68%, indicated the usefulness of direct selection for yield improvement.

Khan *et al.* (2016) studied 24 bottle gourd genotypes during the summer season of 2013 to assess variability in 12 quantitative traits and showed significant variation for all characters. They estimated very high variability was recorded for fruit yield (GCV 63.07%, PCV 63.75%), number of fruits per plant (GCV 59.31%, PCV 60.25%), node to first staminate and pistillate flower anthesis (GCV 38.93%-39.49%), fruit length (GCV 32.45%), and fruit circumference (GCV 28.89%), suggesting strong genetic diversity in these traits. Heritability was very high for all characters, ranging from 78% (number of branches) to 99% (fruit length, fruit circumference, node to first pistillate flower), indicating low environmental influence. High genetic advance was found for fruit yield (128.56%), number of fruits per plant (120.25%), node to first pistillate flower anthesis (80.73%), and fruit length (66.35%), implying predominance of additive gene action. They concluded that direct selection would be most effective for improving fruit yield, fruit length, fruit circumference, and early flowering traits in bottle gourd.

Harika *et al.* (2012) evaluated 25 bottle gourd genotypes in Karnataka and displayed a wide variability for earliness, fruit traits, and yield. The number of primary branches ranged from 4.50 (Kaveri) to 12.67 (Sarika), with an average of 8.89, while vine length at 90 DAS ranged from 376.67 cm (Elina) to 748.33 cm (Anand Bottle gourd-1). For earliness genotypes, NBBL-12 possessed the highest, which showed first female flowering at 45.83 days and first harvest at 52.83 days, whereas Sarika was late (75 days). For fruit traits, fruit length ranged from 9.18 cm (Elina) to 58.92 cm (Anand Bottle gourd-1), and fruit diameter from 6.25 cm (Kaveri) to 16.33 cm (Thar Samridhi). For quality traits like total soluble solids (TSS), it varied between 2.35° Brix (Champion) and 6.13° Brix (NBOH-1). Yield-contributing characters also varied greatly, with the number of fruits per vine ranging from 3.17 (Elina) to 14.50 (Gaja), contributing to the highest fruit yield in Gaja (41.68 t/ha) and the lowest in Champion (10.29 t/ha). They showed that a higher

number of fruits per vine (14.50) was recorded in Gaja with an average fruit weight of 1104.84 g, which accounted for a higher fruit yield per vine (15.81 kg) and fruit yield per hectare (41.68 t/ha).

Husna *et al.* (2011) reported significant genetic variability among 31 bottle gourd genotypes during the Rabi season of 2008-09 at SAU, Bangladesh. They recorded wide variability among the studied genotypes, with yield per plant ranging from 10.5 to 39.6 kg (mean 21.54 kg) and showed the maximum variation with GCV 52.02% and PCV 54.35%. Fruit weight exhibited wide variability, ranging from 1.25 to 2.80 kg (mean 1.99 kg) with GCV 38.61% and PCV 41.17%, followed by the number of fruits per plant, ranging from 5 to 16 fruits (mean 10.42) with GCV 29.16% and PCV 33.54%. High heritability coupled with high genetic advance was observed for yield per plant (h^2 = 91.60%, GA% = 131.43) and fruit weight (h^2 = 87.97%, GA% = 95.61), indicated predominant additive gene action and suggesting that direct selection for these traits would be highly effective.

2.2 Correlation and Path Analysis Studies

Yield in vegetable crops such as bottle gourd is a complex quantitative trait governed by many morphological, physiological, and biochemical attributes. Since yield is not an independent character but rather the outcome of multiple component traits, improvement in yield depends on understanding the nature of the association among these component traits. Therefore, studying the relationship between yield and its associated traits becomes essential for identifying appropriate selection indices in bottle gourd breeding.

Correlation analysis is one of the most widely used biometrical tools to determine the strength and direction of association between two or more variables. A correlation coefficient estimates whether an improvement in one trait will directly or indirectly affect another trait (Cruz and Regazzi, 1997). Genetic correlations arise mainly due to pleiotropy and, to a lesser extent, linkage disequilibrium and are important because selection for one trait often leads to a correlated response in other traits (Hallauer & Miranda, 1982). Phenotypic correlations reflect the combined effects of genetic and environmental interactions, whereas genotypic correlations measure only inheritable relationships and therefore provide more reliable information for selection. However, correlation alone does not reveal whether the association between traits is due to a true causal relationship or via the influence of another character. Since yield attributes are often interdependent, correlations may sometimes give misleading conclusions (Grafius, 1959; Khairwal *et al.*,

1999). To resolve this issue, Wright (1921) introduced path coefficient analysis, which was later adopted in plant breeding by Dewey and Lu (1959). Path analysis partitions the total correlation into direct and indirect effects and thus quantifies the relative contribution of each yield component to the dependent character, usually yield per plant. This method helps breeders identify traits with true direct influence on yield, making it more informative than simple correlation.

Path coefficient analysis has proved valuable in vegetable crops, including bottle gourd, as it highlights traits that exert a direct positive influence on yield, such as fruit number, fruit weight, fruit width, flesh thickness, etc. Hence, integration of correlation and path analysis allows plant breeders to select yield-enhancing traits more precisely, even when traits show interdependence. Various studies have successfully utilized these techniques in bottle gourd improvement programs to identify major yield determinants and formulate effective selection strategies.

Rathore *et al.* (2025) evaluated 30 bottle gourd genotypes and estimated correlation and path analysis using key yield-related traits. Their study showed that fruit yield per plant exhibited highly significant positive correlations with fruit width (r = 0.396), average fruit weight (r = 0.817), and number of fruits per plant (r = 0.799), suggesting that these are the major determinants of yield. In contrast, traits related to earliness, such as days to first fruit setting and days to first fruit picking, showed weak to negative associations with yield. Path coefficient analysis indicated that average fruit weight (0.694), number of fruits per plant (0.536), and fruit width (0.013) exerted the highest direct positive effects on yield per plant, indicating their primary role in yield improvement. Meanwhile, traits like days to first fruit picking (-0.187) and days to first fruit setting (-0.0043) contributed negative direct effects, indicating that delayed fruit development may reduce yield. These proved that genotypes with greater fruit weight, wider fruit diameter, and higher fruit number, coupled with earliness in fruit development, will be most effective for improving yield in bottle gourd.

Bashir *et al.* (2024) studied 77 bottle gourd genotypes in an augmented RCBD during kharif 2022 at Srinagar and reported highly significant differences for all 25 traits and reported that ample genetic variability was present among the studied genotypes. Fruit yield (t ha^{-1}) showed significant positive association with fruit yield $plant^{-1}$ (rp = 0.99, rg = 0.98), fruit weight (0.821, 0.817), vine length (0.625, 0.640), number of primary branches

(0.581, 0.640), number of fruits plant^{-1} (0.376, 0.388), node number at which first male flower appeared (0.218, 0.276), number of female flowers plant^{-1} (0.338, 0.360) and fruit diameter (0.299, 0.328). Moreover, genotypic path analysis further revealed that fruit yield plant^{-1} (0.78), fruit weight (0.502), number of primary branches (0.401), number of fruits plant^{-1} (0.218), node number at first male flower (0.218), number of female flowers plant^{-1} (0.212) and fruit diameter (0.214) exerted the highest positive direct effects on yield ha^{-1}. Whereas days to first male and female flowering and days to anthesis of first male flower had small negative direct effects, suggested that selection should focus primarily on yield plant^{-1}, fruit weight, more primary branches, greater fruit number and favorable flowering node position to develop high-yielding bottle gourd genotypes under temperate Kashmir conditions.

Hegde *et al.* (2024) evaluated F_3 and F_4 progenies of the bottle gourd cross GH-28 × Pusa Santushti and reported that fruit yield per hectare showed strong positive genotypic correlations with number of primary branches (0.778 and 0.904), average fruit weight (0.974 and 0.856), number of fruits per vine (0.995 and 0.682) and leaf width (0.943 and 0.836) in F_3 and F_4 generations, respectively. In contrast, days to first harvest (-0.624 and -0.784), days to first female flower opening (-0.926 and -0.661), node to first female flower (-0.524 and -0.650) and days to first male flower opening (-0.858 and -0.510) were negatively associated with yield, indicating that early flowering and higher number of fruits favour productivity. Path coefficient analysis also proved that traits such as fruit yield per plot (1.078 and 0.581), along with yield components like number of fruits per vine and average fruit weight, exerted high positive direct effects on fruit yield per hectare in both generations, indicated these characters were key selection criteria for improving yield in segregating bottle gourd populations.

Singh *et al.* (2022) investigated twenty bottle gourd genotypes and found that fruit yield (q/ha) showed significant and positive correlations with number of fruits per plant (0.810, 0.785), vine length (0.513, 0.479), number of primary branches (0.384, 0.365), fruit girth (0.284, 0.270), number of leaves (0.229, 0.222), average fruit weight (0.060, 0.063), and fruit length (0.011, 0.013), indicating their strong contribution toward yield. In contrast, yield showed significant negative associations with days to first flower initiation (-0.314, -0.313), days to first fruit set (-0.332, -0.314), days to first fruit harvest (-0.434, -0.418), and days to 50% flowering (-0.221, -0.201), suggesting that early flowering and fruiting favor higher productivity. Path coefficient analysis further revealed high positive direct

effects for number of fruits per plant (0.7511), fruit length (0.2004), vine length (0.1818), fruit girth (0.1269), number of leaves (0.1191), and number of primary branches (0.0659), making these traits were reliable selection criteria for yield improvement in bottle gourd breeding programs.

Kumari *et al.* (2021) reported that number of fruits per vine was the most important yield determinant in bottle gourd, showed highly significant positive correlation with yield per plot (rp = 0.952) and with number of primary branches per vine (rp = 0.930), whereas days to first harvest had a strong negative correlation with yield (rp = -0.804). Average fruit weight (rp = 0.775), fruit girth (rp = 0.711) and fruit length (rp = 0.699) also displayed positive associations with yield, indicating that both fruit size and fruit number contribute to productivity. Path analysis further confirmed that number of fruits per vine exerted the maximum direct positive effect on yield (0.727), followed by average fruit weight (0.567) and fruit length through strong indirect effects (via fruit weight and fruit girth). Vine length, days to first harvest and fruit girth had negative direct effects, suggesting they should be used only for indirect selection, whereas emphasis should be placed directly on fruit number per vine, fruit weight and fruit size traits for yield improvement in bottle gourd.

Abhishek *et al.* (2020) reported that fruit yield per plant in bottle gourd showed a strong positive association with fruit yield per plot (r = 0.988 P; 1.003 G) and number of fruits per plot (r = 0.233 P; 0.927 G). Vine length exhibited strong positive correlations with number of nodes per vine (r = 0.901 P; 0.996 G) and number of branches (r = 0.890 P; 0.966 G), whereas number of fruits per plot showed negative correlations with days to male flowering (r = -0.382 G), days to female flowering (r = -0.253 G), vine length (r = -0.284 G) and number of branches (r = -0.463 G). Path analysis revealed that fruit yield per plot (direct effect = 1.014), number of branches (0.174), number of nodes (0.050), and number of fruits per plot (0.001) exerted positive direct effects on yield, while vine length (-0.204) and days to male flowering (-0.010) contributed negative direct effects. Thus, number of branches, number of nodes, fruits per plot and fruit yield per plot were identified as key traits for improving bottle gourd yield.

Kunjam *et al.* (2019) carried correlation and path analysis of nine bottle gourd during summer season. They reported that fruit yield in bottle gourd showed high positive and significant correlations with days to first male flower and fruit girth at both genotypic and

phenotypic levels, and with vine length, number of fruits per plant, average fruit weight and crop duration at the genotypic level, indicating that late first male flowering, vigorous vine growth, larger fruit size and prolonged cropping period were all associated with higher yield. Path coefficient analysis revealed that the strongest positive direct effects on yield were exerted by average fruit weight (2.96), node number at first female flower (2.76), days to first female flower (1.06), node number at first male flower (1.37), days to first fruit harvest (0.60), and fruit girth (0.23), whereas traits like fruit length, days to first male flower, branch number, days to 50% flowering, crop duration, and number of fruits per plant showed negative direct effects. The authors concluded that direct selection for high average fruit weight, favorable node positions of first male and female flowers, earlier first fruit harvest and larger fruit girth would be effective for developing high-yielding bottle gourd genotypes under Chhattisgarh conditions.

Mahapatra *et al.* (2019) conducted correlation and path analysis of eight six (86) genotypes and five check varieties at Vegetable Science division, IARI, New Delhi. They reported that fruit yield per plant showed highly significant positive associations with average fruit weight (r = 0.720), number of fruits per plant (r = 0.661) and fruit diameter (r = 0.319), indicating these as major yield-contributing traits. Yield exhibited significant negative correlations with days to opening of first female flower (r = -0.229) and days to first fruit harvest (r = -0.211), suggesting that delayed flowering and late harvesting reduce yield. They further estimated path coefficient analysis revealed that number of fruits per plant exerted the highest direct positive effect on yield (1.261), followed by fruit diameter (0.0533), while average fruit weight contributed indirectly to yield through fruit diameter and fruit number. Negative indirect effects were observed for fruit diameter via ovary length (-0.0040) and fruit length (-0.223), but no trait showed a strong negative direct effect. These findings indicated that selection for yield can rely on direct selection of fruit number and size traits.

Sree *et al.* (2019) evaluated 30 bottle gourd genotypes and reported that fruit yield per vine had significant positive correlations with number of fruits per vine (P 0.784 ; G 0.858), average fruit weight (P 0.365; G 0.515), and node number at first female flower (P 0.337; G0.401), while internodal length showed a negative genotypic association with yield (-0.415). The genotypic path analysis revealed high positive direct effects of days to first male flower appearance (1.2869), number of fruits per vine (0.8454), average fruit weight (0.4014), number of primary branches per vine (0.2963), node at first female

flower (0.3820), days to first fruit harvest (0.1129), vine length (0.1286), and fruit girth (0.7287) on fruit yield per vine, whereas internodal length (-0.3457) and fruit length (-1.0230) possessed negative direct effects. These results indicated that selection on higher fruit number, fruit weight, favorable flowering behavior, and better vine and branching traits would be effective for yield improvement in bottle gourd.

Panigrahi *et al.* (2018) conducted a comprehensive correlation analysis of 37 bottle gourd genotypes, demonstrated strong traits interrelationships for effective yield-oriented breeding. The study revealed that fruit yield per vine and per hectare had highly significant positive correlations with major yield components, particularly number of primary branches (rp 0.21; rg 0.29), vine length (rp 0.26; rg 0.37), number of fruits per vine (rp 0.42; r_g 0.50) and fruit length (rp 0.12; r_g 0.27), indicating that improvement in these traits is directly and important association with higher productivity. Days to first male and female flower were strongly correlated (rg 0.903), and days to first female flower had a strong correlation with days to first fruit harvest (r_g 0.953), indicated that strong correlation on phenology. Moreover, fruit diameter expressed strong negative associations with fruit length (rg -0.489) and vine length (rg -0.484), indicating their potential in fruit morphology. The authors demonstrated branching behaviour, fruit number and fruit size were the most influential determinants traits of yield.

Sultana *et al.* (2018) reported that fruit yield in bottle gourd showed strong significant positive correlations with number of fruits per plant (r = 0.884), branches per plant (r = 0.833), fruit weight (r = 0.368), and 100-seed weight (r = 0.378), indicating that these characters contribute substantially to yield. In contrast, yield exhibited negative associations with days to first male flower opening (r = -0.122), days to first female flower opening (r = -0.290), days to harvest (r = -0.291), and fruit length (r = -0.182), suggesting that early flowering and shorter harvesting duration enhance productivity. Path coefficient analysis revealed that the number of fruits per plant (0.93) had the highest positive direct effect on yield, followed by fruit weight (0.467), days to first female flower opening (0.011), and 100-seed weight (0.01), while fruit length (-0.011) and days to first male flowering (-0.009) showed small negative direct effects. These results indicated that selection for higher fruit weight and more fruits per plant would be most efficient in improving bottle gourd yield.

Varalakshmi *et al.* (2018) reported that fruit yield per hectare in bottle gourd showed a significant positive genotypic and phenotypic correlation with fruit number per vine (rg = 0.792; rp = 0.689) and fruit yield per vine (rg = 1.003; rp = 0.876), indicating these traits as the most reliable yield indicators. Path analysis further revealed that fruit number per vine contributed the highest direct positive effect on yield (0.812), followed by fruit weight (0.407), fruit length (0.339), fruit width (0.310), and fruit yield per vine (0.249). Days to first female flowering (0.224) and vine length (0.173) also had smaller but positive direct effects. These results suggested that yield improvement should focus on indirect selection through fruit number, fruit weight, fruit length, and fruit yield per vine.

Muralidharan *et al.* (2017) evaluated 24 bottle gourd genotypes and demonstrated that fruit yield per vine was significantly and positively correlated with fruit flesh thickness (0.522) and fruit weight (0.644), indicating these traits as strong contributors to yield. Path analysis supported this observation, revealing high positive direct effects showed by fruit weight (1.329), fruit width (0.723), number of seeds per fruit (0.691), days to female flower anthesis (0.442), and fruit flesh thickness (0.251) on yield. These findings suggested that selection based on heavier fruits, thicker flesh, and greater seed content can enhance yield efficiency.

Thakur *et al.* (2017) evaluated 73 bottle gourd genotypes and found fruit yield had strong and highly significant positive correlation with number of fruits per plant (rp = 0.760, rg = 0.956) and average fruit weight (rp = 0.687, rg = 0.777), but negatively associated with crop duration (rp= -0.429, rg -0.495). Earliness and flowering traits were positively interrelated, while fruit girth showed association with late flowering and fruit number. Path analysis revealed the highest positive direct effects on yield from number of fruits per plant (0.552), days to first male flowering (0.329) and average fruit weight (0.310), whereas days to first female flowering (-0.500) and fruit girth (-0.334) had strong negative effects. The study concluded that number of fruits per plant and average fruit weight were the most reliable selection criteria for improving yield in bottle gourd.

Deepthi *et al.* (2016) studied 24 bottle gourd genotypes and found that fruit yield per vine had significant positive correlations with tendril length (r = 0.59), number of nodes per vine (0.55), number of primary branches per vine (0.56), total vine length (0.54), internodal length (0.23), number of fruits per vine (0.51), fruit weight (0.72), fruit diameter (0.75), number of seeds per fruit (0.76) and 100-seed weight (0.75), indicating

these traits as important yield-contributing characters. In contrast, yield showed negative associations with days to first male flower appearance (-0.17), days to first female flower appearance (-0.22), node at first male flower (-0.21), node at first female flower (-0.30) and days to first fruit harvest (-0.08), suggesting that earlier flowering and fruiting enhance yield potential. Genotypic path analysis further revealed that total vine length (3.33), number of fruits per vine (0.60), fruit weight (0.90) and fruit diameter (0.25) exerted high positive direct effects on yield per vine, whereas number of nodes per vine (-1.71), internodal length (-1.36), number of seeds per fruit (-0.44) and 100-seed weight (-0.48) had negative direct effects, confirmed that direct selection for longer vines, more fruits per vine, and heavier, thicker fruits would be effective for yield improvement in bottle gourd.

Mashilo *et al.* (2016) evaluated 36 South African bottle gourd landraces and used correlation and path analysis to identify key traits for improving fruit and seed yield. They found that number of fruits per plant (NFPP) was strongly and positively associated with number of male flowers (NMF), number of female flowers (NFF), plant height (PHT) and number of branches (NB), while number of seeds per fruit (NSPF) showed positive correlations with PHT, NMF, NFF, NB and fruit weight (FW). Path analysis revealed that FW had a very high direct positive effect on NSPF (0.96), and NFF had a high direct effect on NFPP (0.92), while DW showed a remarkable direct positive effect on NSPF (0.47). Based on these relationships, the authors concluded that simultaneous selection for higher FW and increased NFF would be effective for improving both seed yield and fruit yield in bottle gourd, and they identified landraces BG-06, BG-07, BG-09, BG-11, BG-13, BG-24, and BG-67 as promising parental material for breeding programs.

Janaranjani and Kanthaswamy (2015) conducted correlation and path coefficient analysis of 13 genotypes with 18 traits. They reported that fruit yield per vine in bottle gourd showed a significant positive association with fruit flesh thickness, number of fruits per vine and number of pickings, with number of fruits per vine exhibiting the strongest correlation ($r = 0.676$). Path analysis revealed that number of fruits per vine had the highest positive direct effect on yield (0.916), followed by days to first female flower opening (0.800), fruit cavity (0.381), fruit weight (0.374) and days to first harvest (0.192), whereas traits like fruit length (-0.370), days to first male flower opening (-1.103) and primary branches (-0.189) had negative direct effects. These findings suggested that

selection for number of fruits per vine, thicker flesh, early female flowering, larger fruit cavity and higher fruit weight would be most effective in improving yield in bottle gourd.

Singh *et al.* (2012) analyzed 14 early season bottle gourd genotypes and observed that fruit yield per plant showed a strong, significant positive genotypic correlation with number of fruits per plant (r = 0.942) revealed that this trait as the most influential determinant of yield. Days to 50% flowering and fruit breadth had significant negative associations with yield, indicating that late flowering and wider fruits may reduce productivity. Path coefficient analysis also demonstrated that number of fruits per plant exhibited the highest direct positive effect on yield (direct effect = 1.212), followed by days to 50% flowering (0.450) and fruit weight (0.077) at the genotypic level. Moreover, their positive direct effects, days to 50% flowering and fruit weight had negative correlations with yield due to high negative indirect effects through fruit number. Fruit length showed a notable indirect contribution to yield via fruit number and fruit breadth, suggesting its usefulness as a supportive selection trait. The study concluded that fruit number per plant should be the key selection criterion for yield improvement in early-season bottle gourd, followed by fruit weight and fruit length.

Husna *et al.* (2011) investigated 31 bottle gourd genotypes and reported that fruit yield per plant had a strong, highly significant positive correlation with number of fruits per plant (rg = 0.900; rp = 0.887) and fruit weight (rg = 0.781; rp = 0.737). This indicates that both traits are the major yield determinants. Fruit breadth also showed a positive correlation with yield (rg = 0.374; rp = 0.359), whereas the ratio of male and female flowers exhibited a positive but weak association (rg = 0.167). Path coefficient analysis revealed that the number of fruits per plant had the maximum direct positive effect on yield (0.680), followed by fruit weight (0.453), fruit length (0.087), and the ratio of male to female flowers (0.042). Traits such as number of male flowers (-0.009), number of female flowers (-0.004), and fruit peduncle length (-0.083) exhibited negative direct effects, but their indirect positive effects through fruit number and fruit weight resulted in an overall positive association with yield. The residual effect (0.117) indicated that nearly 90% of yield variability was explained by the studied traits, highlighting the reliability of these parameters for selection.

2.3 Stress Tolerance Indices and Their Role in Parent Selection

Several researchers have proposed many stress tolerance indices for identification of stress-tolerant cultivars; however, few are more useful for selection of heat tolerant genotypes in bottle gourd. The tolerance index (TOL) was defined as the difference between grain yield under normal and stress conditions. The mean productivity index (MP) is defined as the average yield of genotype under optimum (Yp) and stress conditions (Ys) (Rosielle & Hamblin, 1981). Fernandez *et al.* (1992) developed the stress tolerance index (STI), which identifies tolerant genotypes under optimum and heat stressed conditions. It is based on the geometric mean production index. Fischer and Wood (1979) introduced the relative stress index (RSI) during drought stress in wheat varieties. Farshadfar *et al.* (2013) used harmonic mean (HM) in on wheat–rye disomic addition lines, as it is the ratio of a doubled product of genotypes yield and their sum under both conditions. The mean relative performance (MRP) is another stress index. The yield stability index (YSI) was calculated as the ratio between the yield under stress and normal conditions. Gavuzzi *et al.* (1997) introduced the yield index (YI) as the ratio of yield of genotypes under normal and the mean yield of all genotypes under stress conditions. Basavaraj *et al.* (2021) used percent yield reduction (PYR) in their research on low phosphorus stress in rice. High MP, STI, GMP, HM, YSI and YI values, as well as low values for the TOL, SSI, RSI and PYR are better ways for the stable and tolerant genotypes selection Pour- Aboughadareh *et al.* (2019).

Seepal *et al.* (2025) evaluated 143 field pea genotypes under normal and late sown heat stress environments to evaluate heat tolerance. The studied genotypes ranging from 1.81 to 31.06 g under normal and 0.27 to 11.80 g under heat stress. The mean seed yield declined from 13.54 g plant^{-1} (Yp) to 4.01 g plant^{-1} (Ys), with mean reduction of 68.9%. The stress indices revealed wide genetic variation of TOL (0.67-27.93), MP (1.47–17.37), GMP (1.39–16.45) and STI (0.01–1.48). The correlation analysis showed that MP, GMP, STI and YSI were strongly and positively associated with Ys, whereas HSI was negatively associated, confirming their value as reliable selection criteria. The PCA analysis further strengthened these findings, with PC1 (57.21%) and PC2 (40.26%) together explained 97.46% of total variation, effectively distinguished heat-tolerant from susceptible genotypes. The genotypes EC-341743, P-1679, P-1384-3, P-179 and P-781 consistently exhibited superior index scores and yield stability, indicating their suitability as donors for breeding heat-resilient field pea.

Poudel *et al.* (2024) studied 20 elite wheat lines under optimum and delayed-sowing heat stress conditions and found a mean grain-yield reduction of 45.29% under heat stress. The correlation analysis of stress tolerance indices showed that yield under irrigated conditions (Yp) was highly and positively associated with TOL (r = 0.657), MP (r = 0.916), GMP (r = 0.917), and STI (r = 0.836), while yield under heat stress (Ys) correlated strongly with YSI (r = 0.694), MP (r = 0.855), GMP (r = 0.853), and STI (r = 0.927), indicating that MP, GMP, and STI are reliable selection indices. The principal component analysis revealed that PC1 and PC2 explained 67.91% and 32.03% of variation (cumulative 99.94%), with PC1 representing a high-yielding stable axis and PC2 as a heat-susceptibility axis, and biplot PCA classification identified NL 1402, NL 1488, NL 1447, NL 1445, NL 1506, NL 1503, NL 1501, and NL 1512 as the most stable and high-performing genotypes recommended for cultivation and breeding in heat-prone environments.

Lamba *et al.* (2023) evaluated 50 wheat genotypes over two years under normal and late-sown heat-stress conditions and reported significant genotype variation for all major heat-stress tolerance indices. Across environments, combined ANOVA revealed highly significant genotypic variation, confirming wide diversity for heat adaptability, while late sowing caused a substantial decrease of grain yield, indicating the strong detrimental effect of heat stress. The correlation analysis showed that Tolerance Index (TOL) and Stress Susceptibility Percentage Index (SSPI) were negatively associated with stressed yield (Ys), whereas indices such as STI, MP, GMP, HM, and MRP showed strong positive correlations (r > 0.70) with both optimal (Yp) and stressed yield (Ys), making them reliable indicators for selecting genotypes with stable performance. The multivariate analyses strengthened these findings revealed that the first two principal components (PC1 and PC2) effectively separated tolerant from susceptible genotypes, and biplot plus cluster analysis consistently placed HD 2967, WH 1249, HI 1617, WH 1202, WH 1021, and WH 1142 as top-performing, heat-tolerant, and high-yielding genotypes across both environments. The results demonstrated that combined use of STI, MP, GMP, and HM provides a good indicator and strategy for selected genotypes capable of maintaining productivity under increasing temperature stress.

Seymen *et al.* (2023) evaluated 48 pumpkin genotypes (44 inbred lines + 2 hybrids + 2 local cultivars) across irrigated and non-irrigated field trials. The results showed that water stress dramatically reduces seed yield with mean Yp = 156.1 kg under irrigation vs Ys = 32.2 kg under stress; and approximately 80% reduction. Multivariate and correlation

analyses identified STI, GMP, and MP are the most reliable indicators for dual performance, with Ys correlating very strongly with HAM (r = 0.992), GMP (r = 0.942), STI (r = 0.927) and DI (r = 0.934), while Yp correlated highly with TOL (r = 0.876) and MP (r = 0.927). Principal component analysis achieved 65.7% (PC1) and 32.7% (PC2) of variance with cumulative 98.4%, and both PCA and Ward clustering consistently categorized a set of promising tolerant genotypes included G9, G40, G32, G36, G5, G11, G22, G30, G37 and G13. The commercial hybrids G1 and G2 clustered with these tolerant lines, while a separate cluster of genotypes (e.g. G8, G10, G24–26, G42–46) were water-sensitive.

Devi *et al.* (2021) evaluated twenty-five (25) heat-responsive spring wheat genotypes across two seasons under optimum field conditions (OFC) and two heat-stress conditions and demonstrated clear genetic variation for grain yield and heat-stress indices. Mean yields declined from 118 g/plot (OFC) to 69.3 g (HSC1) and 48.8 g (HSC2), corresponding to approximately 40% and 60% yield reductions, respectively. The combined ANOVA showed highly significant genotype and condition effects ($P < 0.01$). The study revealed mean productivity (MP), geometric mean productivity (GMP), stress tolerance index (STI) and yield index (YI) were positively and strongly associated with grain yield under stress, while stress susceptibility index (SSI) and tolerance index (TOL) were negatively associated with yield, indicating that MP, GMP and STI were more reliable selection criteria for identifying heat-tolerant, high-yielding genotypes.

Kumar *et al.* (2020b) assessed 35 mungbean genotypes over two years under summer heat stress and kharif normal conditions to evaluate yield-based heat-stress indices. Heat stress involved markedly higher temperatures (up to 39–41 °C) and revealed significant genetic variation for all indices. Stress yield (Ys) showed strong positive correlations with STI (r = 0.868), GMP (r = 0.834), and MP (r = 0.735), while SSI was negatively correlated (r = −0.594), indicating its limited usefulness for selecting broadly adapted genotypes. Genotypes IPM-02-4 (Ys ≥ Yp; SSI = 0.08), NDM-12-308, and SML-1186 consistently performed well under stress, with multivariate (3-D and clustering) analyses confirming their superiority. The study recommended prioritizing GMP, MP, and STI supported by multivariate visualization for effective selection of heat-tolerant mungbean, while cautioning against reliance on any single index or Yp alone.

Gull *et al.* (2019) evaluated 40 genotypes of cowpea under non-stress and stress environments for tolerance-based screening indices. The mean yield dropped sharply from 30.28 g to 20.36 g per plant with 32% yield reduction due to heat stress. Stress tolerance indices such as SSI, TOL, MP and STI showed inconsistent genotype rankings, but their transformation into score-based scales (SSIs, TOLs, STIs, MPs) produced very strong correlations with the original indices (r = 0.992-0.995). The newly developed combined stress indices YSSI (resilience) and YPSI (productivity), explained stress and non-stress yield variation with high precision (R^2 = 0.801 and 0.947, respectively), enabling clear discrimination among genotype classes. Highly resilient and productive genotypes such as C18, C11, C25, C6 and C7 exhibited only 11–16% yield loss, whereas susceptible lines including C12, C16, C26 and C39 caused reductions exceeding 50–60%. They also classified genotypes into the four response groups ranged from superior (Class A) to poor (Class D).

Jha *et al.* (2018) assessed 78 chickpea genotypes under normal and late-sown heat-stress conditions and reported substantial yield variation, with a number of lines possessed comparatively high performance under heat stress conditions. Stress tolerance indices such as Mean Productivity (MP), Geometric Mean Productivity (GMP), Yield Index (YI), and Stress Susceptibility Index (SSI) showed that heat-tolerant genotypes consistently combined high MP and GMP values (e.g., IPC 06-11: MP 287.5, GMP 280.6; RSG 888: MP 271.5, GMP 261.3) with low SSI (<1), such as JAKI 9218 (SSI 0.60) and ICCV 07118 (SSI 0.35). The yield index (YI) recorded superior performers, where genotypes like Pusa 240 (YI 1.71), IPC 06-11 (YI 1.64), and RVG 203 (YI 1.28) recorded the heat-tolerant check ICC 92944 (YI 1.20). Principal component analysis classified the six indices into two components, explaining PC1 61.9% and PC2 37.1% of total variation, effectively categorizing tolerant from susceptible genotypes types. The findings indicated that MP, GMP, YI, and low SSI were reliable, practical selection tools for identifying heat-tolerant germplasm for screening thermotolerant chickpea genotypes under changing climates.

Mashilo *et al.* (2017) evaluated 12 bottle gourd landraces under irrigated (NS) and drought-stressed (DS) field conditions to establish a practical, yield-based selection framework. Mean fruit yield declined from 23.2 t ha^{-1} under irrigation to 8.75 t ha^{-1} under drought, representing a 62% reduction, with drought intensity of 0.61. Yield ranged from 14.2–44.3 t ha^{-1} in NS and 3.48–12.94 t ha^{-1} in DS, and variability was high (CV 31–

33%). Drought stress accelerated phenology, with 50% male flowering occurring earlier (54 vs. 59 days) and maturity advanced by 9 days, indicating a drought-escape response. Principal component analysis (PCA) showed STI, GMP, and MP as the most informative indices (PC1 = 69.7%, PC2 = 30.0%; cumulative 99.7%), supported by TOL, YI, and HARM. Integrated combined ranking identified genotypes GC, BG-78, and BG-52 as stable, high-yielding across environments, while BG-79, BG-31, and BG-67 performed best under drought, with BG-79 showing only 24% yield loss, supported STI, GMP and MP-based selection for drought-resilient breeding.

Jha *et al.* (2016) assessed drought tolerance in 34 chickpea genotypes (13 desi and 21 kabuli) under irrigated and moisture-stress conditions and displayed yield-based indices that can effectively differentiate tolerant lines. Using six indices like Mean Productivity (MP), Geometric Mean Productivity (GMP), Yield Index (YI), Stress Susceptibility Index (SSI), Tolerance Index (TOL), and Superiority Measure (SM), they identified genotypes such as FLIP03-100, FLIP05-123C, FLIP03-98C, IPC2009-102, and IPC2009-186 as superior performers, with higher MP and GMP values under stress (e.g., IPC2009-102: GMP 785 g; IPC2009-186: GMP 747.2 g). The correlation analysis revealed strong positive associations among MP, GMP, and YI (r = 0.995, 0.996, and 0.989, respectively), while SSI and TOL were closely related (r = 0.877) and negatively correlated with yield. PCA analysis reduced the six indices into two major components explaining 97.9% of total variation (PC1 = 84.63%; PC2 = 13.34%), categorized tolerant and sensitive genotype groups. Cluster analysis also grouped genotypes into four clusters, enabling identification of high-yielding, stress-resilient lines suitable for breeding. The indices MP, GMP, and YI were recorded as good criteria for screening drought-tolerant chickpea genotypes.

Meena *et al.* (2015) evaluated 15 wheat varieties over two seasons under normal and restricted irrigation to identify stable drought-tolerant genotypes using yield and stress tolerance-based indices. Moisture stress caused marked yield losses, with stress intensity increasing from 0.24 in a mild year (2010–11) to 0.54 in a severe drought year (2011–12). Grain yield under irrigation ranged from 48.6–61.4 t ha^{-1} and declined to 29.4–40.9 t ha^{-1} under stress, with NI-5439 performing consistently well in both conditions (61.4 and 40.9 t ha^{-1}). STI was the most effective discriminator (NI-5439 = 0.81; Raj-3765 = 0.67; PBW-343 = 0.66) and, along with MP and GMP, showed strong positive correlations with both irrigated and stressed yields (r = 0.89–0.93; $p < 0.001$). Drought-tolerant varieties also

recorded SSI < 1 (e.g., NI-5439 = 0.78), and maintained better physiological stability with smaller reductions in tiller number, chlorophyll content, and thousand-grain weight. The study confirmed STI, MP, GMP, and SSI were reliable selection criteria, identifying NI-5439, Raj-3765, WH-147, and HD-2733 as stable performers across moisture regimes.

Yücel & Mart (2014) evaluated 10 chickpea genotypes over two years under normal and late-sown (drought) conditions at Adana, Turkey to identify reliable selection criteria for drought tolerance. Drought stress reduced seed yield by about 43%, and genotype effects were highly significant for key stress indices (GMP, YI, YSI, DSI, DTE, and STI). The exotic line FLIP 98-108 C performed best, combining high MP (2,069 kg ha^{-1}), GMP (2,016 kg ha^{-1}), STI (99), and YI (140), followed by FLIP 98-63 C (MP 1,790; GMP 1,737; STI 73). In contrast, FLIP 98-42 C was most susceptible, showing low MP (1,313), GMP (1,106), YSI (30%), and high DSI (162) and TOL (1,409 kg ha^{-1}). STI strongly predicted productivity (R^2 = 0.95 with MP) and explained 84% of YI variation, while higher TOL was associated with poor yield stability. The authors recommended FLIP 98-108 C and FLIP 98-63 C as drought-tolerant and high MP, GMP, STI with low TOL and DSI are effective indicators for selecting drought-resilient chickpea in Mediterranean environments.

Anwar *et al.* (2011) reported significant genetic variation among 20 wheat genotypes for grain yield under irrigated (Yp= 3745.8 kg ha^{-1}) and drought-stressed conditions (Ys = 3157.9 kg ha^{-1}), along with all major drought tolerance indices. The estimated high heritability for Yp (67.4%), Ys (74.7%), STI (72.7%), GMP (72.4%), and MP (71.6%) indicated strong potential for selection. Their correlation analysis showed that Yp was positively and strongly associated with MP (r = 0.83), HM (r = 0.77), GMP (r = 0.80), STI (r = 0.80), and k1STI (r = 0.97), while Ys had similarly strong correlations with MP (r = 0.77), HM (r = 0.84), GMP (r = 0.81), STI (r = 0.79), YI (r = 1.00), and k2STI (r = 0.95). Conversely, TOL and SSI showed negative and poor associations with Ys, confirmed their limited usefulness in identifying truly tolerant genotypes. The genotypes 2, 4, 6, 7, 9, and 13 recorded as superior performers under both irrigated and stressed environments. The investigation concluded that indices such as MP, HM, GMP, STI, and modified STI are more reliable indicators for stress tolerance than TOL and SSI and provide an effective selection framework for breeding drought-resilient wheat.

2.4 Line × Tester Analysis for Earliness and Yield Components

The line × tester analysis is an alternate hybrid breeding approach to appraise a large number of inbreds at a time as compared to diallel crosses (Kempthorne, 1957) for the detection of appropriate parents and crosses based on their general and specific combining ability effects (Iqbal *et al.*, 2019). The line × tester design is widely recognized for determining the relative ability of several female and male parents to create desirable hybrids. The combining ability status of the genotypes will indicate how effectively they combine with a particular genotype to produce potential and productive populations. Combining ability analysis provides the information for selection of better parents and cross combinations for their exploitation (Sprague and Tatum 1942). The Line × Tester mating design described by Kempthorne (1957) assists breeders by providing information related to the combining ability of genotypes (both parents and hybrids) and the nature of the gene activity involved. This experiment analyzed eight traits using combining ability analysis to determine the extent of GCA and SCA variance for the traits collectively, as well as the GCA and SCA effects for individual parents and hybrids. The line × tester analysis is a highly effective method for forecasting the general combining ability (GCA) of parental lines and for identifying appropriate parents and crosses with greater specific combining ability (SCA). The prevalence of overdominance gene action for most traits suggests that heterosis breeding would be highly effective for bottle gourd improvement. These findings highlight the potential of utilizing the identified parents and hybrids in future breeding programs to enhance yield and quality in bottle gourd.

Singh *et al.* (2025) investigated general combining ability (GCA) for yield and component traits in bottle gourd using a line × tester design comprising 16 lines, 4 testers and 64 crosses, evaluated for 13 agronomic and yield-related characters. The pooled analysis of variance revealed highly significant GCA effects for most traits, including vine length, number of leaves, fruit length, fruit girth, average fruit weight, number of fruits per plant and yield (q ha^{-1}), indicating the predominant role of additive gene action in trait expression. Among the lines, Narendra Dharidar, Narendra Rashmi, Punjab Long and NDBG-132 exhibited as superior general combiners, each exhibiting significant positive GCA effects for 5–6 key traits, notably yield and its major components. These parents consistently showed favorable GCA for number of fruits per plant and yield, which are primary determinants of productivity in bottle gourd. Among the testers, Arka Bahar and Narendra Madhuri were identified as the best general combiners, expressing positive and

significant GCA effects for 6–8 traits, including average fruit weight, number of fruits per plant and yield (q ha^{-1}). The magnitude and consistency of GCA effects across multiple traits suggest that these parents possess stable and heritable additive genetic potential. The study demonstrated that selection of parents based on GCA is an effective strategy for improving yield and yield-contributing traits in bottle gourd, and revealed the identified high-GCA parents as valuable genetic resources for use in selection-based breeding programs aimed at sustainable yield improvement.

Yadav *et al.* (2025) studied combining ability and gene action for yield and quality traits in bottle gourd under salt-affected soil (pH > 8) using a line × tester design with 9 lines, 3 testers, and 27 F_1 hybrids, evaluated over two Zaid seasons (2020–21). Pooled analysis showed that NDBG-13 (GCA = 1.57) and NDBG-Sel-1 (GCA = 0.75) were the best general combiners for fruit yield per plant, while Narendra Rashmi (GCA = 0.20) was the most effective tester, indicating the importance of additive effects in parent choice. Several hybrids like Narendra Pooja × Pusa Naveen, NDBG-13 × Narendra Rashmi, NDBG-Sel-1 × Narendra Rashmi, and Narendra Kamna × Narendra Rashmi were exhibited consistently high and significant SCA effects for yield and related traits across seasons. Variance analysis revealed that SCA variance exceeded GCA variance for most traits, including fruit yield per plant ($\sigma^2s = 0.54$ vs. $\sigma^2g = 0.16$), number of nodes per vine, and picking duration, with dominance ratios >1 and low predictability ratios. The results indicated predominance of non-additive gene action and overdominance, supported heterosis breeding as a more effective strategy than direct selection for improving bottle gourd performance under saline conditions.

Patel *et al.* (2023) assessed combining ability for yield and related traits in bottle gourd using a line × tester design (7 lines, 3 testers, 21 F_1s) during February season. The analysis of variance revealed highly significant ($P < 0.01$) GCA mean squares for most traits, indicating the presence of exploitable additive genetic variability among the parents. ANOVA showed highly significant GCA and SCA effects for most traits ($P < 0.01$), confirming substantial genetic variability. SCA variance exceeded GCA variance for nearly all characters except earliness traits (days to first male/female flower and first harvest) indicating a major role of non-additive gene action. Despite this, strong and consistent additive effects were evident for key yield components. The line BRBG-22-1 was the best general combiner for fruit yield per vine (GCA = +2.29), along with positive GCA for primary branches (+1.93) and fruits per vine (+1.13). Among testers, Rajendra

Chamatkar showed favorable GCA for fruit length and weight, while Swarna Sneha was positive for fruits per vine (+0.24). The study supported parent selection based on GCA and identified BRBG-22-1 and Rajendra Chamatkar as valuable parents for selection-based yield improvement in bottle gourd.

Ahmad *et al.* (2022) evaluated general combining ability in bottle gourd using a line × tester design with 18 lines, 3 testers, and 45 F_1 hybrids across two summer seasons (2020–2021) at Meerut, India. ANOVA showed highly significant GCA effects for all 12 yield and yield-related traits, confirming the predominance of additive gene action. Several parents showed strong and consistent GCA effects across traits. Among parents, IC-310188 was the best general combiner for fruit yield (+40.53 q ha^{-1}), followed by IC-394736 (+30.24 q ha^{-1}), IC-398541 (+29.60 q ha^{-1}), and IC-321410 (+28.33 q ha^{-1}). For yield components, IC-321410 showed very high GCA for average fruit weight (+185.84 g) and primary branches (+2.11), while IC-541393 was superior for fruits per plant (+2.99) and vine length (+0.94 m). Among testers, Narendra Rashmi was the best general combiner for fruit yield (+14.75 q ha^{-1}), and Pusa Naveen showed positive GCA for fruit length, branches, and fruits per plant. The study highlighted the effectiveness of GCA-based parent selection and identified IC-310188, IC-321410, IC-394736, and Narendra Rashmi as valuable donors for yield improvement in bottle gourd.

Singh *et al.* (2022) assessed the combining ability of diverse genotypes of watermelon in a line × tester mating design at the Vegetable Research Farm, Panjab Agricultural University, India. There were 40 F_1 hybrids, 10 lines, and 4 testers were evaluated in Feb-May, 2019, for yield and component traits. The combining ability research determined that both general and specific combining ability effects were significant for all attributes. The ratio of σ2SCA: σ2GCA revealed the dominance of non-additive gene effects for internode length, days to appearance of 1st female flower, fruit length, fruit width, yield/plant, number of fruits/plants, average fruit weight, vine length, TSS, and vitamin C. Among the parents, lines WM-10, yellow-2, and Barmer, as well as tester KFF 1-1-2, performed well in terms of fruit yield and component attributes and were treated as good general combiners. The hybrids W-6-3-3-3-2 × KFF 1-1-2, WM-20 × KFF 1-1-2, and Yellow-2 × KFF 1-1-2 were produced greater TSS content and yields.

Khot *et al.* (2021) used line (10) × tester (3) models to investigate the parents and hybrids in bottle gourd to combine for growth, earliness, and yield. The study revealed that the

SCA effect of crosses and the general combining ability effects of parents were highly significant. In terms of fruit yield per vine, parents Bot.G-4, Bot.G-7, and Kolkata collection were good general combiners. For vine length, number of branches, days to first female flower, days to first harvest, and sex ratio, Line Bot.G-6-2 showed notable GCA effects. There were notable SCA effects on vine length and fruit yield per vine in the Cross Bot.G-6-2 × Arka Bahar. Identifying the parents or hybrids status based on combining ability effects over multiple component characters is crucial for effective selection.

Masud *et al.* (2021) assessed general and specific combining ability in bottle gourd using a line × tester design (7 lines × 3 testers; 21 F_1s) at BARI, Gazipur, Bangladesh. Highly significant ($P < 0.01$) variation among genotypes indicated substantial genetic variability. Additive gene action predominated for yield and related traits. Among lines, 62-12-1-2-2-2 and 59-1-1-1(A)-7 emerged as strong general combiners, recording positive GCA effects for number of fruits per plant (+1.23, +1.68) and yield per plant (+0.93, +2.16), along with desirable negative GCA for days to first male and female flowering, indicating earliness. Among testers, BG0059 was the best general combiner, with positive GCA for fruits (+1.40) and yield (+2.08) and negative GCA for days to flowering. The study highlighted 62-12-1-2-2-2, 59-1-1-1(A)-7, and BG0059 as promising parents for yield and earliness improvement through additive gene action.

Hadiya *et al.* (2020) examined the combining ability of bottle gourds utilizing a line × tester mating pattern across three environments. They determined that both additive and non-additive gene expression play significant roles in determining fruit output per vine and other features. Except for fruit length, all features were expressed primarily by non-additive gene activity, whereas other traits were expressed through additive gene action. The parents ABGS 11-23, JBGL 42, JBGL 43, NDBG 104, NDBG 132, NDBG 604, ABG 1, and Pusa Naveen all had a strong GCA effect in the desired direction for fruit output per vine and several fruit yield-related traits. The best five crosses involving average or good general combiner parents showed good SCA effect in the desired direction for fruit yield per vine.

Mishra *et al.* (2019) evaluated twelve agronomic and yield traits in bottle gourd using four parental lines (NDBG-744, Pusa Naveen, NDBG-707, and NDBG-749-2) and their F_1 hybrids. The study showed that NDBG-744, Pusa Naveen, and NDBG-707 were good general combiners for number of fruits and fruit yield per plant, while NDBG-707 and

Pusa Naveen also contributed to earliness. In contrast, NDBG-749-2 and Pusa Naveen were associated with smaller fruit size. Combining ability analysis revealed that both additive and non-additive gene actions influenced the traits, but non-additive effects (dominance/epistasis) were predominant, with evidence of over-dominance. The asymmetric distribution of dominant and recessive genes and absence of distinct gene groups indicated polygenic inheritance of yield and related traits in bottle gourd.

Janaranjani *et al.* (2016) assessed the breeding value of bottle gourd parents using a line × tester combining ability approach to evaluate the scope of heterosis breeding for commercial F_1 hybrid development. Nine lines and four testers were crossed to produce 36 hybrids, which were evaluated for growth and yield traits. ANOVA revealed significant variation among lines and testers for most traits, while line × tester interactions were significant for nearly all characters, indicating substantial genetic diversity. In all cases, SCA variance exceeded GCA variance and the GCA:SCA ratio was < 1, demonstrating the predominance of non-additive gene action. Based on mean performance and GCA effects, Punjab Long, Kalyanpur Long Green, and Pusa Naveen among lines, and NDBG-164 and Samrat among testers, were identified as superior parents for yield and related traits, supporting the effectiveness of heterosis breeding in bottle gourd.

Raut and Mishra (2015) conducted a line × tester study in bottle gourd during summer and Kharif 2008 and found that specific combining ability variances were higher than general combining ability variances and indicating non-additive gene action. The study showed that JBG 9 was an effective general combiner for all traits except days to first male flower appearance, number of female flowers per plant, and fruit setting percentage. Five crossing crosses, JBG4 × T1, JBG6 × T1, JBG9 × T1, JBG5 × T3, and JBG11 × T3, were the most effective specific combiners for yield and yield components.

Selvi *et al.* (2015) evaluated combining ability for yield and related traits in pumpkin (*Cucurbita moschata*) using a line × tester design with 12 lines and 3 testers. For all characters, SCA variance exceeded GCA variance, indicating the predominance of non-additive gene action. Among parents, Vadhalagundu local and Kasi Harit were the best general combiners for earliness traits (days to first female flower, first female flowering node), sex ratio, fruits per vine, and quality traits such as carbohydrate and total carotenoid content, as well as fruit yield per vine. Among testers, CO2 showed significant positive GCA for earliness, sex ratio, fruits per vine, total carotenoids, and yield, while Arka

Suryamukhi was a good general combiner for days to first harvest, carbohydrate content, and carotenoids. Among hybrids, Kasi Harit × Avinashi local was the best specific combiner for fruits per vine, earliness, flesh thickness, carotenoid content, and yield, followed by Vadhalagundu local × CO2, confirming the effectiveness of heterosis breeding for yield and quality improvement in pumpkin.

Wani *et al.* (2009) studied combining ability effects for 14 traits in bottle gourd (*Lagenaria siceraria*) using a line × tester mating design involving 15 lines and 3 testers, resulting in 45 hybrids. Significant general combining ability (GCA) and specific combining ability (SCA) effects were observed among parents and hybrids, respectively. The line NDBG-123 exhibited high GCA effects for 10 traits, followed by SHBG-11 (8 traits), KLG (5 traits), and SHBG-12 (3 traits). Among the crosses, L-10 × SHBG-11 and Kalyanpur Long Green × SHBG-11 showed high SCA effects for 6 traits each, while NDBG-123 × SHBG-11, Local Long Green × SHBG-11, and L-27 × BGS-50 displayed significant SCA effects for 5 traits each.

Sirohi and Rana (2008) conducted combining ability analysis in bottle gourd using eight parents and 28 F_1 hybrids. Among parents, Pusa Sandesh (P2) showed superior general combining ability (GCA) for earliness traits including days to first female flower opening and harvest, while Punjab Komal (P3) performed best for male flowering. For yield-related traits, Samrat Long (P5) exhibited highest GCA for fruit weight and total yield, whereas Pusa Naveen (P1) showed maximum GCA for fruit number per plant. Among hybrids, Pusa Sandesh × Arka Bahar (P2×P8) displayed the highest specific combining ability (SCA) for yield components including fruit number, weight and total yield per plant, making it particularly valuable for hybrid breeding programs. These findings provided valuable insights for selecting parental lines and hybrid combinations in bottle gourd improvement.

Maurya *et al.* (2004) conducted combining ability analysis on bottle gourd [*Lagenaria siceraria*] genotypes, including 10 lines, 3 testers along with 30 F_1 hybrids, utilizing line × tester analysis. The variance attributed to general combining ability (GCA) exceeded that of specific combining ability (SCA) for all traits, with the exception of the number of primary branches per main stem and days to first male anthesis, indicating the presence of additive gene action. NDBG-15 exhibited significantly positive general combining ability effects for the number of primary branches per main stem. Pusa Naveen demonstrated

effective general combining ability across 10 distinct traits, including early fruit yield per plant. PBOG-61 and PBOG-91 demonstrated effective general combining ability for various characters, including early fruit yield per plant, among the testers. PBOG-40 × PBOG-91, Pusa Naveen × PBOG-61, PBOG-84 × PBOG-54, DVBG-2 × PBOG-91, Punjab Komal × PBOG-54, and PBOG-15 × PBOG-61 exhibited a significantly positive specific combining ability effect for high early fruit yield per plant.

Sharma *et al.* (2002) conducted a line × tester analysis in bottle gourd (*Lagenaria siceraria*) using 10 lines and 3 testers, evaluating 30 F_1 hybrids for twelve agronomic traits. The study identified KBG-16 as the best general combiner for early maturity and yield traits, while GH-13 showed strong GCA for vine growth and fruit weight. PSPL and Arka Bahar were superior for fruit length and fruit diameter, respectively. Among hybrids, GH-10×G-2, GH-9×PSPL, and GH-13×G-2 exhibited significant SCA effects, indicating potential for heterosis breeding. These findings highlighted the importance of combining ability studies in selecting superior parents and hybrids for bottle gourd improvement.

2.5 Diallel Cross Analysis for Earliness, Yield-Contributing and Quality Traits

The diallel cross was first introduced by J. Schmidt in livestock breeding and later adopted in plant breeding during the 1950s, with the first reported application in plants by Jinks and Hayman (1953). A diallel cross involves all possible matings among a set of parents; when parents, selfs, and reciprocals are included, it is termed a complete diallel (Griffing, 1956a). This mating design has been widely used in plant breeding to study genetic variation and combining ability in both self- and cross-pollinated crops using inbred or non-inbred parents (Jinks and Hayman, 1953; Gardner and Eberhart, 1966).

Diallel analysis is especially useful for highly heritable traits, as it provides early insight into parental potential and heterotic patterns, making parent selection more effective (Sharma, 1998; LeGouis *et al.*, 2002). Depending on breeding objectives, different diallel schemes may be employed, ranging from parents and F_1s with or without reciprocals to F_1s alone. A major outcome of diallel analysis is the estimation of general combining ability (GCA), reflecting average parental performance, and specific combining ability (SCA), indicating cross-specific deviations (Ghosh and Das, 2003). A high GCA:SCA ratio suggests predominance of additive gene action, while a low ratio indicates dominance or epistasis (Griffing, 1956b).

Although diallel analysis relies on assumptions such as homozygous parents, equal gene frequencies, and absence of epistasis which are often unrealistic for quantitative traits, it remains a powerful and widely applied mating design when results are interpreted cautiously (Hayman and Mather, 1955; Hallauer and Miranda, 1982).

A major contribution of diallel analysis is the estimation of general combining ability (GCA), which reflects the average performance of parents, and specific combining ability (SCA), which measures deviations of particular crosses from expected values (Ghosh and Das, 2003). Statistically, GCA corresponds to main effects, while SCA represents interactions (Zary, 1980). Griffing (1956b) proposed two models for diallel analysis: Model I (fixed effects), for defined sets of parents where only GCA and SCA are meaningful, and Model II (random effects), for parents as a sample from a population, where variance components are emphasized. A high GCA:SCA ratio suggests a predominance of additive effects, while a low ratio indicates dominance or epistatic effects (Griffing, 1956b; Wassami *et al.,* 1986). Thus, when appropriately applied, diallel analysis provides plant breeders with valuable insights into gene action, combining ability, and heterotic patterns, thereby enhancing the efficiency of crop improvement programs (Christie and Shattuck, 2010).

2.5.1 Combining Ability for Yield and Yield-Contributing Traits in Bottle Gourd

Selection of potential parents, based on genetic information and their combining ability, is a key step in crop improvement. The concept of combining ability was first proposed by Sprague and Tatum (1942) in corn. They concluded that general combining ability (GCA) is largely associated with additive gene action, whereas specific combining ability (SCA) arises from dominance, epistasis, and genotype × environment interaction. Knowledge of general (GCA) and specific combining ability (SCA) is essential in hybrid breeding, as it guides the selection of superior parents and promising crosses. Parents with high SCA are particularly valuable for enhancing agronomic traits and maximizing heterosis in F_1 progeny.

General combining ability (GCA) reflects a parent's average performance across hybrid combinations and primarily measures additive gene action. Specific combining ability (SCA) represents the deviation of a particular cross from the expected performance based on the GCA of its parents, capturing non-additive genetic effects. Positive GCA indicates above-average progeny, while SCA can be positive or negative and always refers to a

specific cross. Partitioning genetic variation into GCA and SCA helps breeders make informed decisions in crop improvement programs (Sprague and Tatum, 1942).

The most common designs for combining ability studies are line × tester and diallel analysis. Diallel method (Griffing, 1956a) is widely used to evaluate parental performance in hybrids and to assess the nature and magnitude of gene action controlling quantitative traits. GCA effects represent the fixable, additive component of genetic variance and guide the selection of superior parents, while SCA effects reflect non-fixable, non-additive variance and inform potential hybrid performance (Sprague, 1966). Diallel crosses are an effective strategy to assess general (GCA) and specific combining ability (SCA) among potential parents, though they require many crosses and high-quality data for precise estimates (Burow and Coors, 1993). They are widely used in plant breeding to evaluate GCA, SCA, variance components, and heritability. According to Baker (1978), if SCA mean squares are not significant, progeny performance can be predicted from GCA, selecting parents with the highest values. If SCA is significant, specific interactions must be considered to determine progeny performance.

The main goal of breeding programs is to increase crop yield by selecting parental lines based on their combining ability (Baker, 1978). The ratio of general to specific combining ability (GCA: SCA) in diallel analysis provides insight into the nature of gene action controlling quantitative traits (Quick, 1978). A high GCA:SCA ratio indicates a predominance of additive genetic effects, while a low ratio reflects the importance of non-additive effects. Thus, higher GCA variance than SCA variance suggests additive gene action, whereas greater SCA variance indicates dominance or non-additive effects (Baker, 1978), and comparing GCA and SCA variances helps identify the predominant genetic effects controlling a trait. Studies on combining ability in bottle gourd have highlighted the importance of both additive and non-additive gene action for yield improvement during the heat-stressed kharif and summer seasons.

Rahaman *et al.* (2025) evaluated 30 bottle gourd genotypes (7 parents, 21 F_1s, and 2 checks) during the 2024 monsoon season at Gazipur, Bogura farm, and Dinajpur field using a 7 × 7 half-diallel in RCBD. Analysis of variance revealed significant differences among parents, hybrids, and their interactions across all eleven studied traits. Combining ability analysis showed that both GCA and SCA variances were highly significant. GCA/SCA ratios were estimated below 1 for most traits, including yield per plant (0.33)

and harvest duration (0.30), indicating the predominance of non-additive gene action, while node of first male flower and fruit diameter had ratios above 1, suggesting a greater role of additive effects. The highest positive and significant GCA effects for harvest duration (2.42), fruit per plant (0.68), and yield per plant (1.21) were recorded in BG714 and identified as superior parents for improving these traits. The parents, BG722 and BG717, were exhibited significant positive values of 0.07 and 0.04, respectively, for fruit weight. The significant and negative GCA effects were observed for all the parents except HAJARI (0.39) and BG725 (0.26) for fruit diameter and HAJARI was marked good general combiner, followed by BG725 for increasing fruit diameter. The crosses BG714 × BG722 and BG714 × BG717 exhibited the highest SCA and heterosis for yield and fruit number. Among the hybrids, HAJARI × BG719 and BG719 × BG722 demonstrated superior mean performance and standard heterosis for yield and early harvest, indicated their potential for commercial cultivation.

Keshari and Singh (2024) assessed eight parents and 28 F_1s (half-diallel) during the summer season of 2023 in the Vegetable Research Center, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. They showed that both GCA and SCA variances were significant. They revealed that for earliness, negative GCA effects were observed in Pusa Sandesh (-1.97), Kashi Kirti (-1.22), and Pusa Samridhi (-0.91) while higher SCA possessed in crosses including Pant Lauki-3 × NDBG-104, Pant Lauki-3 × Pusa Samridhi, and NDBG-104 × Pusa Sandesh. For average fruit weight, Kashi Kirti (150.33) was the best general combiner, and Kashi Kirti × Kashi Kiran (738.88) the best hybrid. For fruits per plant, Pusa Samridhi (0.59) and Narendra Rashmi (0.49) were superior GCA parents, while Pusa Samridhi × Kashi Kiran (3.33) and Pant Lauki-4 × Kashi Kirti (3.17) were promising crosses. For yield per vine, Kashi Kirti (0.49) and Pant Lauki-4 (0.37) were recorded as the best GCA lines, while Kashi Kirti × Kashi Kiran (3.11) and Pant Lauki-4 × Pusa Samridhi (2.42) ranked highest for SCA. For yield per hectare, Pant Lauki-4 (22.58) and Narendra Rashmi (11.68) showed strong GCA effects, while Pusa Samridhi × Kashi Kiran (166.72) and Pant Lauki-4 × Kashi Kirti were the best crosses in terms of SCA effects. The investigation concluded that Pant Lauki-4 × Kashi Kirti and NDBG-104 × Pusa Sandesh as promising heterotic hybrids for commercial utilization.

Saryam *et al.* (2024) conducted a diallel analysis with 23 bottle gourd genotypes (6 parents, 15 F_1s, and 2 checks) during the kharif seasons of 2022 and 2023 at JNKVV, Jabalpur, India, focusing on quality traits. Pooled data revealed that cross JBG-4 × JBG-5 exhibited the highest total soluble solids (3.93 °Brix) and ascorbic acid content (14.48 mg/100 g), followed by JBG-2 × JBG-4 (3.77 °Brix, 13.72 mg/100 g ascorbic acid). Yield per plant was highest in JBG-4 × JBG-5, which also showed the strongest heterosis for TSS and ascorbic acid content. Combining ability analysis identified JBG-4 and JBG-2 as superior general combiners for TSS (2.92, 3.71 °Brix), ascorbic acid (14.01, 12.30 mg/100 g), and rind thickness, while JBG-4 × JBG-5 was the best specific combiner for quality traits TSS and ascorbic acid content. The results suggested that JBG-4 × JBG-5 and JBG-2 × JBG-4 are highly promising for improving fruit quality and yield in bottle gourd and could be recommended for commercial cultivation.

Mkhize *et al.* (2023) evaluated combining ability and heterosis of bottle gourd among eight drought-tolerant genotypes using a half-diallel design (28 F_1s) under both drought-stressed (DS) and non-stressed (NS) conditions across two seasons (2020-21 and 2021-22) in South Africa. The research revealed that significant general combining ability (GCA) and specific combining ability (SCA) effects were detected for fruit yield per plant, with strong GCA × environment and SCA × environment interactions, highlighted greater environmental influence. Parents BG-58 and GC were identified as promising general combiners for fruit yield per plant under drought stress, while GC performed well under non-stress environments. A number of crosses (e.g., BG-27 × BG-79, BG-79 × BG-52, BG-80 × BG-70, BG-80 × GC, BG-70 × GC) expressed favorable SCA effects under drought stress, and while other crosses (e.g., BG-81 × GC, BG-27 × GC, BG-80 × BG-58) were performed good under non-stress conditions. Among the crosses, such as BG-80 × BG-58 and BG-27 × BG-79, exhibited high mid-parent and better-parent heterosis under drought stress, while BG-27 × GC and BG-27 × BG-58, BG-79 × GC, and BG-79 performed high and positive mid-parent and better-parent heterosis for fruit yield per plant under non-stress conditions.

Singh *et al.* (2023) assessed combining ability in fifty-eight (58) bottle gourd genotypes (45 hybrids, 10 parents, and 3 checks) across three environments using Griffing's Method-II, Model-I and reported significant variance among parents, hybrids, and their interactions for all traits and indicating the involvement of both additive and non-additive gene actions, with a predominance of non-additive effects. Significant general combining ability (GCA)

and specific combining ability (SCA) effects were identified for key traits. Inbreds P6, P2, P5, and P9 showed strong GCA for early harvest, number of branches, rind thickness, and yield. For earliness (days to first harvest), inbred lines P6 (–1.86), P2 (–1.66), and P3 (–1.26) showed significant desirable GCA effects, while the hybrids P9 × P10 (–2.16), P4 × P6 (–2.13), and P3 × P8 (–1.94) expressed the highest desirable SCA effects. For fruit diameter, P9 (1.33), P7 (1.05), and P8 (1.05) showed high GCA effects, and P7 × P10 (2.15) and P8 × P9 (1.43) exhibited high SCA. Regarding yield per square meter, seven inbred lines exhibited significant positive GCA effects, with P8 (0.81), P4 (0.68), and P10 (0.51) were the best general combiners, while P6 × P9 (2.71) was the best specific combiner, followed by P6 × P8 (2.01) and P7 × P8 (2.01). The parent P10 (IC-594545) was identified as the best parent and P7 × P8 (VRBG-27-1 × VRBG-11-1) as the best hybrid for yield improvement in bottle gourd.

Mahawar *et al.* (2021) evaluated combining ability and heterosis to identify promising parents and crosses under semi-arid conditions using eight parents crossed in a half-diallel and assessed across four environments during kharif-2016 for further improvement in bottle gourd. Analysis revealed significant GCA and SCA variances for most traits, indicating both additive and non-additive gene actions. The GCA/SCA ratios estimated below one indicated that additive effects were predominated for traits such as days to opening of first female flower (–2.36 to 2.43), days to first fruit set (–2.28 to 2.93), number of nodes at first female flower appearance (–1.04 to 1.29), number of primary branches per vine (–0.79 to 0.78), fruit length (–7.05 to 5.13 cm), fruit girth (–2.33 to 4.01 cm), number of marketable fruits per vine (–1.62 to 1.10), number of pickings (–1.57 to 1.11), and total fruit yield (–6.94 to 5.46 q/ha). Parents PSPL, NR, and PN were exhibited good general combiners for earliness, fruit traits, and yield, while other parents, PSPL and PN contributed to fruit length and PK to fruit diameter. Superior specific combiners with maximum SCA effects included PSPL × NR, PN × PSPL, PN × PS, and PK × AB for various flowering, fruit, and yield traits, indicating their potential for improving component characters and overall fruit yield in specific environments.

Quamruzzaman *et al.* (2020) evaluated seven bottle gourd parents and twenty-one F_1 hybrids from a 7 × 7 diallel at the Horticulture Research Centre, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh, during the Rabi 2018-19 season to assess combining ability for yield and related traits. Highly significant differences were observed among all F_1 hybrids and parental means. Both general combining ability (GCA) and

specific combining ability (SCA) effects were significant, and SCA variances were generally higher than GCA. Among the studied parents, superior general combiners included P1, P2, P6, and P7 for yield; P2, P4, and P5 for days to first harvest; P1, P2, and P7 for fruit length; and P3 and P6 for fruit diameter. Besides this, crosses showing high SCA and potential for heterosis included P2×P7, P4×P7 (days to first harvest), P3×P5, P4×P5 (fruit length), P3×P6, P2×P4 (fruit diameter), and P3×P4, P3×P5, P4×P5, and P4×P7 (yield per plant). These parents and crosses could be exploited for hybrid development, subject to further validation.

Quamruzzaman *et al.* (2019) evaluated combining ability in bottle gourd at the Horticulture Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur, during Rabi 2016-17 season. The analysis revealed highly significant mean squares for both GCA and SCA for yield per hectare, indicating the presence of both additive and non-additive gene action, though the higher magnitude of GCA suggested predominance of additive effects. Among the parents, P1 showed the highest positive GCA (2.78), followed by P3 (2.22) for yield, and P5 (−2.28) was a poor combiner. Among 10 crosses, six exhibited positive SCA effects, with P1 × P3 (7.49), P2 × P3 (4.13), P4 × P5 (4.03), and P2 × P4 (2.95) showing significant positive SCA, indicating both good × good and poor × poor combiner combinations can generate superior hybrids. These results confirmed that selection of parents with high GCA is critical for yield improvement and crosses involving poor × good or poor × poor GCA parents in hybrids with high SCA for fruit yield.

Singh and Singh (2019) conducted a diallel analysis in bottle gourd to investigate the genetic architecture of yield and related quantitative traits, including heterosis, combining ability, heritability, and genetic advance. The study evaluated seven diverse parents and their 42 F_1 hybrids (including reciprocals) in a randomized block design at NDUAT, Faizabad. The analysis revealed significant general and specific combining ability effects for most traits, except node number of first female flower, days to first harvest, and number of branches per plant. Among parents, Pusa Naveen emerged as the best general combiner for key earliness and yield traits, including days to anthesis of male and female flowers, fruit yield per plant, fruit diameter, number of fruits per plant, and internodal distance. Among the crosses, NDBG-202 × L-22, Pusa Naveen × NDBG-240, and NDBG-129 × NDBG-202 showed superior specific combining ability for fruit yield per plant.

Parmar and Pathak (2018) evaluated 28 F_1 hybrids of bottle gourd derived from 8 parents using a half-diallel design at Punjab Agricultural University, Ludhiana, during the 2015 rainy season. Analysis of variance showed significant genotypic differences for most traits except days to first fruit harvest. General combining ability effects were significant for traits such as days to first female flowering, fruit length (112.17), fruit width (4.10), number of fruits per plant (5.58), fruit weight (6276.63 g), marketable yield (1.69), and vine length (5646.10), indicating additive gene action presence in these traits. SCA effects were significant for fruit length (9.40), fruit width (2.82), fruit weight (45.43 g), number of fruits per plant (2.00), marketable yield (2.06), and vine length (59.80), indicating the presence of non-additive gene action. Hybrids from high × low or low × low GCA parents exhibited superior performance and heterosis. Notable good combiners included Punjab Komal, PBOG-7, PBOG-8, Punjab Barkat, and PSPL. The predominance of non-additive gene action in most traits suggested the potential of specific hybrid combinations for developing high-yielding bottle gourd varieties.

Doloi *et al.* (2017) conducted a study of 10 bottle gourd parents and 45 F_1 hybrids during the Kharif season, 2016, at Anand Agricultural University, India, to assess general and specific combining ability for fruit yield and its component traits. The analysis of variance revealed significant differences among genotypes, with GCA and SCA effects indicating that both additive and non-additive gene actions contributed to trait inheritance. Among the studied parents, like ABG 1, ABGS 11-17, and DBG 6, were identified as superior general combiners for fruit yield and related traits, while hybrids such as ABGS 11-23 × DBG 5, ABG 1 × Arka Bahar, and DBG 6 × DBG 5 exhibited high specific combining ability, suggesting their potential for developing high-yielding varieties. The study proved the potential of heterosis breeding in bottle gourd, identifying promising cross combinations for commercial hybrid development under varied environmental conditions.

Shinde *et al.* (2016) analyzed ten parents and 45 F_1s of bottle gourd through a half diallel mating design to assess gene action and combining ability for earliness and yield components across nine quantitative traits and selected DBG 5, Bhagirathi, and NDBG 129 as the best general combiners for yield traits. The mean squares for GCA were significant for all traits, while the σ^2GCA/σ^2SCA ratio indicated a greater role of non-additive gene action in trait inheritance. They reported strong specific combining ability across hybrids, with 20 crosses showing significant negative SCA for days to first female flowering, particularly Samrat × Pusa Summer Prolific Long and Samrat × NDBG 619.

For node to first female flower, 17 crosses recorded desirable SCA, including NDBG 129 × PBOG-89. Similarly, 19 crosses showed significant negative SCA for days to first harvest. Consistently, positive SCA effects were recorded for vine length in 6 hybrids, primary branches in 13 hybrids, fruit length in 14 hybrids, and average fruit weight in 16 hybrids. Among the crosses, fifteen crosses also expressed significant positive SCA for fruit yield, with Samrat × NDBG 619 and Pusa Summer Prolific Long × Pusa Naveen identified as best performers. The combination of high × low and high × high GCA combinations indicated the involvement of additive, dominant, and epistatic gene actions.

Adarsh *et al.* (2015) evaluated nine bottle gourd parents and 36 F_1 hybrids during the kharif 2013-2014 season at Bihar Agricultural University, India, to study general and specific combining ability for earliness and yield components. Analysis revealed significant SCA effects for most characters, indicating the role of non-additive gene action (dominance and epistasis) in hybrid performance. Among the examined parents, Pusa Naveen was identified as a superior general combiner for earliness, vine girth, number of fruits per plant, and fruit yield per plant, while Pusa Naveen × SBBG-31-1 and Pusa Santushti × Pusa Naveen were the best specific combiners for early maturity and high yield. These results demonstrated the potential of these hybrids for developing early-maturing, high-yielding varieties suitable for the Indo-Gangetic plains.

Ray *et al.* (2015) evaluated 10 parents and 45 F_1 hybrids of bottle gourd through half diallel analysis during the Kharif season at Varanasi, India to estimate combining ability for yield and its components. Both GCA and SCA variances were exhibited significant and σ^2gca/σ^2sca ratio <1 for most traits, indicating a predominance of non-additive gene action, whereas fruit length was mainly governed by additive effects. Among parents, Pusa Naveen, NDBG-601, NDBG-625, and NDBG-749-2 showed high positive GCA effects for yield and earliness. The cross P3 × P6 recorded the highest SCA effect for fruit yield per plant (3.62), followed by P4 × P10 and P2 × P9, suggested their potential in hybrid breeding.

Vegad *et al.* (2011) evaluated eight bottle gourd genotypes using half diallel mating design during the summer season to assess general combining ability (GCA) and specific combining ability (SCA) for fruit yield and its component traits. The study reported significant variances for both GCA and SCA for most characters, indicating the importance of both additive and non-additive gene action, with additive effects

predominating as suggested by GCA:SCA ratios greater than unity. Among the parents, ABG-1 was identified as the best general combiner for fruit yield and its contributing traits, followed by Bhagirathi. For hybrids, ABG-1 × VR-2, ABG-1 × Bhagirathi, ABG-1 × JBOGL-01-6, and JBOGL-01-6 × Bhagirathi showed superior specific combining ability, demonstrating their potential in breeding programs for yield improvement.

2.5.2 Heterosis for Yield and Yield-Contributing Traits in Bottle Gourd

Heterosis, or hybrid vigor, is now widely used, which refers to the phenomenon in which the F_1 hybrid obtained by crossing the two genetically dissimilar homozygous gametes or individuals shows the increased or decreased performance for any character over its parental values. It was first recognized by Koelreuter (1763) in tobacco and Datura and later described by Shull (1948) as the "stimulus of heterozygosis." The expression of heterosis may arise from heterozygosity, allelic interactions such as dominance or overdominance, non-allelic interactions (epistasis), or maternal effects. Heterobeltiosis, a term coined by Fonseca and Patterson (1968), refers to the increased or decreased vigor of an F_1 hybrid compared to its better parent. The exploitation of this hybrid vigor, or heterosis, serves as an alternative breeding method to enhance yield per unit area. The magnitude of heterosis depends on the number of heterozygous loci, with greater heterozygosity leading to higher heterosis (East and Hayes, 1912).

Heterosis plays an important role in crop breeding, particularly in cross-pollinated crops, though progress has also been made in self-pollinated species. Based on parents used, heterosis is estimated as (i) mid-parent heterosis (MPH), the superiority of the F_1 over the mean of the parents, and (ii) high-parent heterosis (HPH), the superiority of the F_1 over the better parent. Hybridization is the most effective approach to break yield barriers and evolve high-yielding varieties, but careful selection of parents is critical, since phenotypic superiority alone does not ensure desirable heterosis. Heterosis breeding has proven to be the most successful strategy among available breeding methods, contributing to improvement in productivity, earliness, uniformity, quality, adaptability, and rapid deployment of desirable genes (Riggs, 1988). A considerable degree of heterosis has been documented in bottle gourd and other cucurbits for various traits.

Rahaman *et al.* (2025) evaluated 30 bottle gourd genotypes (7 inbred lines, 21 F_1 hybrids from a 7 × 7 half-diallel, and 2 commercial checks, Diana and Moyna) across three locations during the 2024 monsoon season. Analysis of mean performance and heterosis

identified superior hybrids for earliness traits and yield components. The highest positive heterobeltiosis for yield per plant was 26.37% in HAJARI × BG725, followed by 24.56% (HAJARI × BG719), 24.07% (BG719 × BG722), and 22.21% (HAJARI × BG720). The maximum mean yield was 28.29 kg/plant in HAJARI × BG719, followed by statistically similar 27.77 kg/plant in BG719 × BG722. For earliness, BG719 × BG720 showed the highest negative heterobeltiosis for days to first edible harvest (-15.30%), while BG719 × BG722 recorded the lowest mean harvest duration (58.58 days). Harvest duration among hybrids ranged up to 96.82 days (HAJARI × BG719, HAJARI × BG725, BG719 × BG722), comparable to Diana (96.20 days) and Moyna (94.87 days). Standard heterosis analysis confirmed HAJARI × BG719 as superior for both yield (14.09% and 8.96%) and early harvest, while BG719 × BG722 performed best as an early variety. The study concluded that HAJARI × BG719 and BG719 × BG722 were identified as top-performing promising hybrids for improvement of yield and earliness in bottle gourd.

Saryam *et al.* (2024) studied 23 bottle gourd genotypes, including six parents, fifteen diallel crosses, and two checks, at JNKVV, Jabalpur, during kharif 2022 and 2023 for quality traits. The study revealed significant positive heterosis for total soluble solids recorded in crosses with JBG-4 × JBG-5 (27.16% over mid-parent; 23.43% over better parent) and JBG-3 × JBG-4 (25.86% and 24.11%). For ascorbic acid content, JBG-4 × JBG-5 recorded maximum heterosis (13.08% over mid-parent; 3.45% over better parent). In the case of rind thickness, the most promising crosses were JBG-3 × JBG-4 (54.42% over mid-parent; 54.17% over better parent) and JBG-1 × JBG-3 (46.56% over mid-parent), along with JBG-1 × JBG-4 (43.50% over better parent), indicated their potential for improving fruit quality in bottle gourd.

Masud *et al.* (2021) assessed 21 bottle gourd F_1 hybrids at the Olericulture Division Farm, Horticulture Research Center, BARI, Gazipur, to assess heterosis and combining ability. The analysis showed significant positive heterosis was recorded for most yield-related traits, particularly number of fruits per plant and fruit yield per plant. The highest positive heterosis for fruit number was 190.41% in 59-1-1-1-1-8 × BG0048, followed by 158.26% (59-1-1-1-1-8 × BARI Lau-1) and 140.38% (59-1-1-1-1-1-8 × BG0059). Correspondingly, yield per plant exhibited the highest heterosis 195.27% in 59-1-1-1-1-8 × BG0048 and 149.92% in 59-1-1-1-1-8 × BARI Lau-1, clearly indicated that increased fruit number contributed to higher yield. For earliness traits days to first male and female flower were recorded negative heterosis with maximum values of -13.25 days (59-1-1-1(A)-7 × 48)

and -19.08 days (59-1-1-1(A)-7 × BARI Lau-1), indicating their earliness. Some crosses, such as Pusa Santushti × Sel.8 and Pusa Sandesh × PSPL, also showed desirable earliness, while 62-12-1-2-2-2 × BARI Lau-1 exhibited positive heterosis (22.58%) for fruit weight. The authors concluded 59-1-1-1-1-8 × BG0048, 59-1-1-1-1-8 × BARI Lau-1, and 59-1-1-1(A)-7 × BARI Lau-1 were identified as promising hybrids for commercial exploitation of higher fruit number, yield, and earliness in bottle gourd.

Patel and Mehta (2021) conducted a study on nine diverse bottle gourds [*Lagenaria siceraria* (Mol.) Standl.] parents to develop 36 F_1 and F_2 hybrids using a half-diallel mating design to assess heterosis and inbreeding depression for fruit yield and associated traits. The analysis revealed highly significant differences among parents, F_1's, and F_2's for all characters. High heterobeltiosis for fruit yield per plant was recorded in Arka Bahar × Santosh (79.59%), followed by Punjab Long × Santosh (78.22%), Punjab Long × NDBG-15 (74.88%), Punjab Long × JBOGL-01-42 (70.54%), and Punjab Long × JBGL-43 (69.90%). Standard heterosis for fruit yield was highest in Arka Bahar × Santosh (71.51%), followed by Punjab Long × Santosh (70.19%), Punjab Long × NDBG-15 (49.01%), NDBG-15 × Santosh (48.85%), and Punjab Long × JBGL-43 (45.44%). For number of fruits per plant, heterobeltiosis ranged from 21.95% (Aruna × PBOG-88) to 41.77% (Arka Bahar × JBOGL-01-42), while standard heterosis reached at 40.86% in Pusa Naveen × Santosh. The crosses such as Arka Bahar × Santosh, Punjab Long × Santosh, and Punjab Long × NDBG-15 were identified as highly promising for fruit yield and related traits and revealed that heterosis in bottle gourd strongly influenced by specific parental combinations.

Balat *et al.* (2020) evaluated heterosis in bottle gourd using nine parents and 36 F_1 hybrids across four environments at Junagadh Agricultural University, India, during kharif 2018 and summer 2019. The study focused on both heterobeltiosis and standard heterosis for yield-related traits and revealed significant positive heterosis in seven hybrids over the better parent and three over the standard check. On a pooled basis, seven hybrids over the better parent and three over the standard check exhibited significant positive heterosis. Among the examined crosses, the top five cross combinations exhibited significant and desirable heterobeltiosis across pooled environments, and the crosses were Pusa Naveen × Samrat (55.03%), Punjab Long × DBG 5 (54.30%), Samrat × DBG 6 (44.41%), Punjab Long × Pusa Naveen (42.26%), and ABG 1 × Arka Bahar (40.47%). For standard heterosis, the best crosses in E1 were ABG 1 × Arka Bahar (43.68%), Arka Bahar × Pusa

Naveen (31.36%), NDBG 132 × Arka Bahar (30.38%), Punjab Long × NDBG 132 (29.72%), and NDBG 132 × Samrat (28.24%); for E2 crosses ABG 1 × Arka Bahar (38.84%), Arka Bahar × Pusa Naveen (32.49%), Punjab Long × NDBG 132 (32.12%), NDBG 132 × Arka Bahar (29.40%), and ABG 1 × NDBG 132 (28.31%); in E3, ABG 1 × Arka Bahar (55.46%), Punjab Long × DBG 5 (41.05%), Punjab Long × NDBG 132 (38.65%), Punjab Long × Pusa Naveen (33.62%), and ABG 1 × NDBG 132 (28.38%); and while for E4, Pusa Naveen × Samrat (46.43%), NDBG 132 × Arka Bahar (41.84%), NDBG 132 × Pusa Naveen (36.48%), ABG 1 × Arka Bahar (36.22%), and NDBG 132 × Santosh (35.97%). Across all environments, crosses ABG 1 × Arka Bahar (43.82%), Punjab Long × NDBG 132 (30.28%), and NDBG 132 × Arka Bahar (27.69%) were recorded as consistently significant and desirable standard heterosis.

Mishra *et al.* (2019) investigated heterosis in bottle gourd using 36 F_1 hybrids developed from nine diverse parents through a diallel mating design (excluding reciprocals) for 12 traits, including days to first male and female flower anthesis, node number of first flower appearance, days to first fruit harvest, vine length, primary branches per vine, fruit length, fruit circumference, fruit weight, number of fruits, and fruit yield per vine. Heterosis estimation revealed that fruit yield per vine ranged from -42.02% to 47.92% over the better parent and -44.85% to 54.74% over the standard parent, Pusa Naveen. Among yield and component traits, fruit yield, number of fruits per vine, vine length, and primary branches per vine exhibited the highest heterosis. The top heterotic F_1s for fruit yield were P7 × P9 (54.74%), P1 × P7 (47.43%), and P3 × P7 (46.55%), which also showed significant heterosis for number of fruits per vine along with attractive fruit shape.

Jayanth *et al.* (2019) estimated heterosis to evaluate earliness and vegetative traits employed 6 × 6 half diallel mating system and showed the genotypes possessed significant differences for all the characters. The hybrid from the cross Pusa Naveen x Punjab Komal showed significantly higher negative standard heterosis for earliness, and the hybrid from the cross KBG-16 x Pusa Samridhi showed highly significant heterosis for vegetative traits.

Doloi *et al.* (2018) evaluated 45 F_1 hybrids derived from ten bottle gourd parents using a diallel design (excluding reciprocals) to assess heterosis over the better parent and standard check NDBGH 4. Significant variability was observed among genotypes for all traits studied. Crosses ABGS 11-23 × DBG 5, ABG 1 × Arka Bahar, and DBG 6 × DBG 5

exhibited highly significant positive heterosis for fruit yield per vine over the standard check, whereas ABGS 11-22 × Punjab Komal and DBG 6 × Punjab Komal showed significant negative heterosis for earliness.

Gautam *et al.* (2017) assessed 45 crosses along with their 10 parental lines evaluated through diallel mating design during kharif and rabi seasons to assess the extent of heterobeltiosis and standard heterosis in bottle gourd. The heterosis ranged from -3.84% (P2 x P7) to 64.49% (P5 x P8) in pooled over better parent for yield/vine. The best five crosses, viz., P3 x P9 (67.26%), P5 x P8 (64.49%), P6 x P9 (63.58%), P4 x P5 (60.66%), and P2 x P4 (58.76%) were showed positive and significant heterosis over better parent. The range of standard heterosis was from P4 x P8 (9.80%) to (69.17%) P3 x P9 in pooled analysis. the best five crosses which showed significantly positive heterosis over standard check were P3 x P9 (69.17%), P6 x P9 (65.45%), P5 x P8 (64.49%), P4 x P5 (60.66%) and P7 x P9 (56.80%) for fruit yield/ vine in pooled analysis. These crosses indicated that there was a great scope of heterosis breeding for higher yield in bottle gourd.

Khot (2017) developed 30 F_1 crosses by mating 10 lines with three testers using a line × tester design to evaluate heterosis over the commercial check Warad. Heterosis for vine length ranged from -44.06% to 68.34% at 30 DAS and -57.84% to 38.67% at 60 DAS. Number of branches at 60 DAS showed heterosis from -40.00% to 76.00%, sex ratio from -20.88% to 22.59%, number of fruits per vine from -4.64% to 25.83%, fruit length from -13.43% to 42.56%, fruit diameter from -18.37% to 32.17%, average fruit weight from -18.56% to 5.78%, fruit yield per vine from -10.00% to 22.93%, and fruit yield per plot from -6.03% to 29.92%. The top crosses for fruit yield per hectare were Kolkotta Collection × Samrat (29.93%), Bot.G-6 × Samrat (26.93%), and Bot.G-7 × Arka Bahar (25.98%) over the commercial check.

Adarsh *et al.* (2016) evaluated heterosis in bottle gourd using nine parents and their 36 F_1 hybrids developed through a half-diallel mating design. Analysis of variance revealed significant differences among parents and hybrids for most traits, except days to first pistillate flower anthesis and fruit weight. For earliness, heterosis for days to first pistillate flower anthesis ranged from -22.74% (SBBG-32 × HZP-RC-1) over the better parent to -31.52% (Pusa Naveen × SBBG-31-1) as standard heterosis. Days to first fruit harvest showed -16.95% heterosis in SBBG-31 × HZP-RC-1 over the better parent and -21.12% over the standard check (Pusa Naveen × SBBG-31-1). Fruit yield per vine exhibited

maximum heterosis of 47.79% in HZP-RC-1 × SBBG-11 over the better parent, while Pusa Santushti × Pusa Naveen showed 21.32% standard heterosis over the check variety. These results indicated that specific cross combinations can be exploited for both earliness and high yield in bottle gourd.

Ghuge *et al.* (2016) investigated eight bottle gourd genotypes at the Vegetable Research Farm, Banaras Hindu University during the summer seasons of 2013 and 2014. Twenty-eight F_1 hybrids and their parental lines were assessed for heterosis over mid-parent and the standard check. Among crosses, TC 092372 × VRBG 444 and TC 092372 × VRBG VAR-45 showed -12.6% and -13.5% heterosis, respectively, for days to first staminate flower anthesis, while PSPL × VRBG VAR-45 recorded -14.7% for days to first fruit harvest. IC 093236 × TC 092372 exhibited 48.9% heterosis for fruit length, and IC 093236 × VRBG VAR-45 25.6% for diameter. Average fruit weight was highest in IC 093236 × VRBG 444 (44.6%), fruits per vine peaked in Aditi × PSPL (17.9% over mid-parent; 53.3% over check), and fruit yield per vine was maximum in the same hybrid (68.5%). These findings demonstrate that heterosis in bottle gourd depends on specific parental combinations, with hybrids like Aditi × PSPL, IC 093236 × VRBG VAR-45, and TC 092372 × VRBG 444 showed superior performance for early maturity, fruit traits, and yield components.

Gaykawad (2014) evaluated heterosis in bottle gourd using 36 F_1 hybrids developed from 12 lines and three testers via a line × tester design. Heterosis over the commercial check Warad was substantial for most traits. The study revealed heterosis for number of fruits per vine from -33.33% to 26.67%, fruit length from -25.57% to 24.42%, fruit diameter from -23.58% to 94.13%, average fruit weight from -37.50% to 150.00%, fruit yield per vine from -56.40% to 57.00%, and fruit yield per plot from -24.83% to 176.96%. The top hybrids for yield per hectare were NBBL-12 × Pusa Sandesh (174.97%), IC421962 × Pusa Summer Prolific Long (161.84%), and IC308564 A × Pusa Summer Prolific Long (158.89%), highlighted the potential of these crosses for high-yielding F_1 hybrid development.

Kumar *et al.* (2014) investigated 45 F_1 hybrids along with their 10 parental lines of bottle gourd derived from the half diallel method of analysis to investigate the extent of heterosis for yield and its related traits. The negative heterosis, which is desirable for days to first pistillate flower anthesis, node number of first pistillate flower anthesis, and days to first

fruit harvest, was common in most of the crosses. Significant heterosis was recorded over better parent in F_1 hybrids P8 × P9 (NDBG-625 × NDBG-749-2), P5 × P9 (NDBG-601 × NDBG-749-2), P6 × P9 (NDBG-603 × NDBG-749-2), P1 × P4 (Pusa Naveen × NDBG-517), and P4 × P6 (NDBG-517 × NDBG-603), respectively, as they were recorded to be the five best-performed hybrids for fruit yield per vine. The highest yield recorded by these hybrids due to increased number of fruits per vine. The best performed F_1 hybrid was P8 × P9 (NDBG-625 × NDBG-749-2) which recorded 7.73 kg fruit yield per vine.

Yadav and Kumar (2012) evaluated 36 F_1 hybrids and 15 parental lines of bottle gourd to assess standard heterosis over the check variety Pusa Meghdoot for twelve traits, including flowering, vine and fruit attributes, and yield. Negative heterosis, desirable for earliness traits such as first male and female flower anthesis and node number to first flower, was observed in crosses like DK × NDBG-104, PBOG-22 × Pusa Naveen, and AD-1 × NDBG-104. The positive and desirable heterosis for yield-related traits, including vine length, nodes per vine, primary branches, fruit length, fruit weight, fruits per plant, and total yield, was significant in crosses such as AD-1 × NDBG-104, VRBG-1 × PSPL, VRBG-44 × NDBG-104, VRBG-148 × NDBG-104, and VRBG-44 × Pusa Naveen. Among the crosses, most hybrids exhibited significant heterosis, identified several promising crosses for simultaneous improvement of earliness and yield in bottle gourd.

Kumar *et al.* (2011) investigated heterosis in bottle gourd for yield and its components using eight lines (C-29, C-37, C-74, C-78, C-4, C-55, C-34, C-26) and three testers (Azad Harit, PSPL, and KLG) via a line × tester design. Traits studied included days to fruit setting, fruit length, fruit diameter, number of branches per vine, vine length, number of seeds per fruit, number of fruits per vine, days to maturity, and fruit yield per vine. Among the 24 F_1 hybrids, the crosses C-4 × PSPL, C-34 × PSPL, and C-29 × PSPL exhibited significant desirable heterosis for yield and multiple traits, with heterosis exceeding 40% over the better parent, indicated their potential for high-yielding hybrid development.

Dubey and Ram (2008) evaluated 28 F_1 hybrids developed from eight diverse bottle gourd genotypes at the Vegetable Research Center, GBPUAT, Pantnagar, to study heterosis for yield and associated traits. Significant heterosis was observed for yield over both the local check and better parent. The top-performing hybrid, PBOG61 × PBOG76, exhibited the highest heterosis of 40.2% over the standard parent, indicated its strong potential for commercial cultivation and improvement of yield in bottle gourd.

CHAPTER III
MATERIALS AND METHODS

A total of fifty-eight (58) inbred lines of bottle gourd (*Lagenaria siceraria*) were developed from base populations at the BRAC Agricultural Research and Development Center (BARDC), Gazipur, and the BARC Vegetable Research Center, Dinajpur, under BRAC Seed and Agro Enterprise. These genotypes were advanced to homozygosity through repeated selfing. All genotypes were initially screened under both heat-stressed and non-stressed conditions to identify tolerance levels. From this evaluation, twenty heat-tolerant and moderately tolerant inbreds were crossed using a line × tester mating design, and six diverse, heat-tolerant genotypes were selected. These inbreds were subsequently incorporated into a 6 × 6 full diallel cross to produce F_1 hybrids for the assessment of combining ability, heterosis, heritability, and the genetic basis of yield and yield-contributing traits under heat stress.

The experiments were carried out sequentially during 2022-2025 at the BARC Vegetable Research Center, Dinajpur, Bangladesh, located approximately 10 km northwest of the city center. This chapter outlines the plant materials, experimental design, crop management, data collection, and statistical methods employed in the study.

3.1 Experimental Site, Soil and Climate

The experiments were conducted at the BRAC Vegetable Research Center, Dinajpur, Bangladesh, under BRAC Seed and Agro Enterprise. The site is located approximately 10 km northwest of Dinajpur city and falls within the Old Himalayan Piedmont Plain, designated as Agro-Ecological Zone (AEZ) No. 1. Geographically, the site lies at an altitude of 37.5 m above sea level, positioned at 25°42′ N latitude and 88°39′ E longitude. The climate of the region is subtropical, characterized by hot summers and cool winters, with an average annual rainfall of about 2,500 mm, the majority of which occurs during the monsoon season (June–September). The experimental field soil was classified as sandy loam, moderately fertile, and well-drained, which is favorable for diversified crop cultivation in the region. The soil pH of 5.58 indicates slight acidity, potentially influencing nutrient availability and crop performance. The chemical analysis of the experimental field (0–15 cm depth) revealed 0.06% total nitrogen, 1.17% organic matter, 65.23 μg g^{-1} available phosphorus, 0.17 meq 100 g^{-1} available potassium, 5.92 μg g^{-1} available sulphur,

1.59 meq 100 g^{-1} available magnesium, 3.76 µg g^{-1} available zinc, and 0.70 µg g^{-1} boron (Appendix-I). These analyses were carried out by the Soil Resource Development Institute (SRDI), Nashipur, Dinajpur, prior to the commencement of the experiment.

3.2 Experimental Outline

Four sequential experiments were conducted during 2022-2025 to address the stated objectives of this research and fulfill the requirements of the thesis in Table 3.1.

3.2.1 Experiment-1: Study of Genetic Variability, Correlation and Path Coefficient Analysis under Optimum and Heat Stress Conditions

3.2.1.1 Experimental materials

A total of fifty-eight inbred lines of bottle gourd (*Lagenaria siceraria*) were collected from Bangladesh's agro-ecological zones (AEZ), national and international organizations, AVRDC, universities, and seed companies of India, China, and Thailand. Among the genotypes a number of germplasms were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur Agricultral University (GAU), BADC, and locally adopted popular open pollinated registered genetic stocks that were also employed under study. All the genotypes were selfed for several generations at BRAC Agricultural Research and Development Center (BARDC), Gazipur and BRAC Vegetable Research Farm, Dinajpur by BRAC Seed and Agro Enterprise to attain homozygosity and minimize inbreeding depression. Genotypes were screened under heat-stressed and non-stressed conditions. The principal morphological features, along with the pictorial representations of all fifty-eight genotypes used in the present investigation, were systematically presented in Table 3.2 and Plate 3.1.

3.2.1.2 Experimental seasons and weather conditions

The experimental genotypes were cultivated under optimum (non-stress) conditions during the Rabi season (October 16, 2022) to avoid high temperatures, while for heat stress evaluation was conducted in Kharif-1 season (April 16, 2023) under natural heat stress at open field to ensure exposure to elevated temperatures throughout the growing period. Weather data for both seasons were obtained from the Bangladesh Meteorological Department (BMD), including mean maximum and minimum air temperatures, relative

Table 3.1: Experimental outline of conducted four experiments

Expt. No.	Name of Experiments	Locations	Duration
01	Study of genetic variability, correlation and path coefficient analysis under optimum and heat stress conditions	BRAC Vegetable Research Center, Dinajpur	Optimum: Rabi 2022-23 Natural heat stress (open field): Kharif-1, 2023
02	Screening and identification of heat-tolerant bottle gourd genotypes using stress tolerance indices		Optimum: Rabi 2022-23 Natural heat stress (open field): Kharif-1, 2023
03	Selection of heat-tolerant inbred lines based on combining ability using line × tester analysis in bottle gourd		Crossing: Rabi 2023-24 Evaluation: Kharif-1, 2024 at open field natural heat stress
04	Combining ability and heterosis analysis of selected heat-tolerant genotypes in bottle gourd		Crossing: Rabi 2024-2025 Evaluation: Kharif-1, 2025 at open field natural heat stress

Table 3.2: Morphological features and pictorial representations of the fifty-eight bottle gourd genotypes

Sl No.	Accession No.	Source of collection	Key traits	Pictorial view
1	BG-01	BRAC Seed, Bangladesh	Medium, bottle-shaped, deep green with spotted fruit	
2	BG-02	BRAC Seed, Bangladesh	Medium, bottle-shaped, broad-necked, deep green with white spots	
3	BG-03	BRAC Seed, Bangladesh	Medium-long, fatty fruit, very narrow neck, very light green color	
4	BG-04	BRAC Seed, Bangladesh	Very long, bottle-shaped, deep green-colored spotted fruit	
5	BG-05	BRAC Seed, Bangladesh	Flat round shape, deep green, wilt tolerant, excellent fruit quality	
6	BG-06	Advanta seed, India	Cylindrical and elongated fruit, light green color	
7	BG-07	BRAC Seed, Bangladesh	Medium-sized, bottle-shaped, narrow-necked, spotted green-colored fruit	
8	BG-08	BRAC Seed, Bangladesh	Short-sized, bottle-shaped, deep green-colored fruit,	
9	BG-09	BRAC Seed, Bangladesh	Long, cylindrical-shaped, light green-colored fruit	
10	BG-10	BRAC Seed, Bangladesh	Pear-shaped, high neck, pista green color, tolerant to fusarium wilt	
11	BG-11	BRAC Seed, Bangladesh	Pear-shaped, high and broad neck, light green color, tolerant to fusarium wilt	
12	BG-12	BRAC Seed, Bangladesh	Long bottle-shaped fruit, narrow neck, spotted green-colored fruit	

Sl No.	Accession No.	Source of collection	Key traits	Pictorial view
13	BG-13	Winall Hi-tech, China	Long cylindrical fruits, pista green color, prolific bearing	
14	BG-14	BRAC Seed, Bangladesh	Long, Deep green, narrow neck spotted skin	
15	BG-15	BRAC Seed, Bangladesh	Cylindrical, short-sized fruit, broad and extended neck; spotted deep green colored fruit	
16	BG-16	BRAC Seed, Bangladesh	Cylindrical, short-sized fruit, broad and extended neck; spotted green-colored fruit	
17	BG-17	East west Seed, Thailand	Long cylindrical fruits, deep green with white spots, broad and extended neck tolerant to diseases and pests	
18	BG-18	VNR Seed, India	Cylindrical and elongated fruit, broad and extended neck, pista green color fruit	
19	BG-19	Chakra Seed, India	Short fruit, attractive green color, broad and extended, and prominent neck	
20	BG-20	BRAC Seed, Bangladesh	Oval cone-shaped fruit, pista green color, prolific bearing, tolerant to wilt	
21	BG-21	BRAC Seed, Bangladesh	Bottle-shaped, medium-long, attractive light green-colored fruit	
22	BG-22	BRAC Seed, Bangladesh	Long, thin, bottle-shaped, narrow-necked, spotted green-colored fruit	
23	BG-23	BRAC Seed, Bangladesh	Short bottle-shaped fruit, extended neck, spotted shiny green-colored fruit	
24	BG-24	Bharat Nursery, India	Long cylindrical elongated fruit, pista-green-colored fruit, rain tolerant	
25	BG-25	BRAC Seed, Bangladesh	Bottle-shaped with narrow neck fruit, green color with white spots	

Sl No.	Accession No.	Source of collection	Key traits	Pictorial view
26	BG-26	BRAC Seed, Bangladesh	Bottle shaped fruit, parrot green color, prominent narrow neck	
27	BG-27	BRAC Seed, Bangladesh	Bottle-shaped fruit, spotted green-colored fruits	
28	BG-28	BRAC Seed, Bangladesh	Medium-sized fruit, cylindrical with broad neck, rain tolerant	
29	BG-29	BRAC Seed, Bangladesh	Round shaped, green-colored fruit with white spots	
30	BG-30	Chia Tai Seed, Thailand	Medium-long, cylindrical, elongated shape, very light green color	
31	BG-31	BRAC Seed, Bangladesh	Medium, bottle-shaped fatty fruit, deep green with white spots	
32	BG-32	Bhola, Bangladesh	Cylindrical-shaped, long fruit, spotted deep green fruits, good bearing habit	
33	BG-33	BRAC Seed, Bangladesh	High round fruit, shorter-sized, dark green-colored fruit	
34	BG-34	BRAC Seed, Bangladesh	Bottle-shaped, thin and long curved fruit, green with white spots in fruit skin	
35	BG-35	BRAC Seed, Bangladesh	Very short and cylindrical fruit, bright green color with spots, rain and drought tolerant	
36	BG-36	BRAC Seed, Bangladesh	Bottle shaped medium fruit, green with white spots, prominent broad neck	
37	BG-37	BRAC Seed, Bangladesh	High round-shaped fruit, pista green color, prolific bearing, rain tolerant	
38	BG-38	BRAC Seed, Bangladesh	Cylindrical-shaped long fruit, bright green color with white spots	

Sl No.	Accession No.	Source of collection	Key traits	Pictorial view
39	BG-39	Lion Seed, India	Bottle shaped, short fruit, deep green color, water-logged tolerant	
40	BG-40	Kaysar Seed, India	Round shaped fruit, very light green color	
41	BG-41	BRAC Seed, Bangladesh	Round-shaped, light green-colored fruit	
42	BG-42	BRAC Seed, Bangladesh	Round shaped, green color with white spots, good bearing habit	
43	BG-43	BRAC Seed, Bangladesh	Bottle-shaped, light green color, fatty at blossom end and narrow at the neck,	
44	BG-44	BRAC Seed, Bangladesh	Bottle-shaped, narrow neck, pista green colored fruit, good bearing habit	
45	BG-45	BRAC Seed, Bangladesh	High, round-shaped, spotted, dark green color, drought tolerant	
46	BG-46	BRAC Seed, Bangladesh	High round shaped, deep green color	
47	BG-47	BRAC Seed, Bangladesh	Cylindrical shaped, pista green color, good bearing habit	
48	BG-48	BRAC Seed, Bangladesh	Cylindrical long fruit, spotted green-colored fruit	
49	BG-49	BRAC Seed, Bangladesh	Cylindrical long, green-colored fruit	
50	BG-50	Hejia Hi-tech, China	Bottle-shaped fruit, pista-colored fruit, blossom end fatty and narrow neck	

Sl No.	Accession No.	Source of collection	Key traits	Pictorial view
51	BG-51	BARI, Bangladesh	Bottle-shaped, deep green with white spots, prolific bearing habit	
52	BG-52	BARI, Bangladesh	High round-shaped, bright green, broad neck	
53	BG-53	GAU, Bangladesh	Cylindrical-shaped, medium-long fruit, light green with shiny fruit	
54	BG-54	GAU, Bangladesh	Round shaped, light green, glossy fruit, good bearing habit	
55	BG-55	Thakurgoan, Bangladesh	Flat round-shaped fruit, good bearing, light green color	
56	BG-56	AUS Bangla Seed, Bangladesh	High round-shaped fruit, green and glossy color, good bearing habit	
57	BG-57	AUS Bangla Seed, Bangladesh	Pear-round-shaped fruit, dark green color, good bearing habit	
58	BG-58	AUS Bangla Seed, Bangladesh	Pear-round-shaped fruit, light green color, good bearing habit	



Plate 3.1. Pictorial view of 58 bottle gourd genotypes under study

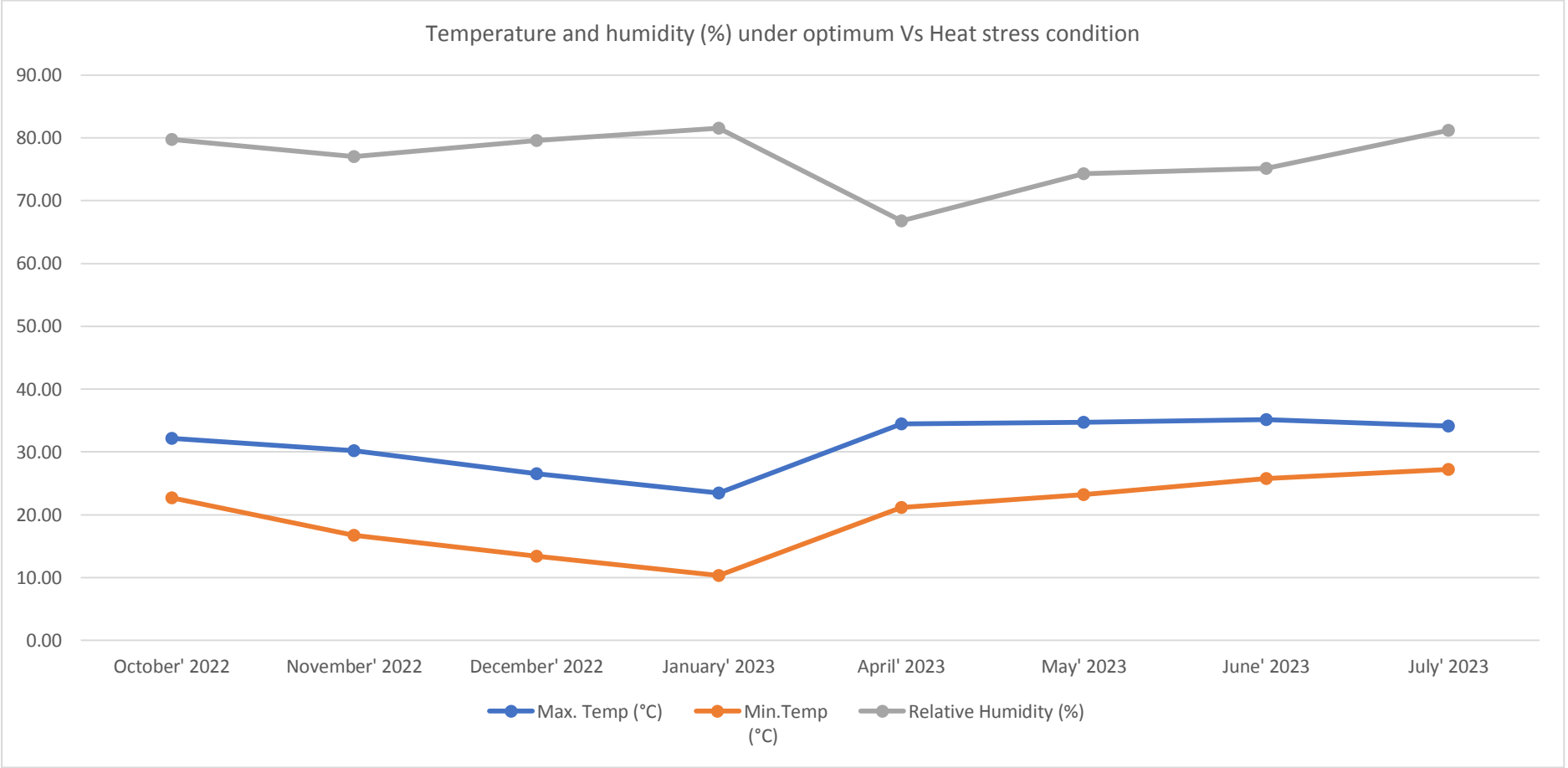


Figure 3.1. Comparative monthly trends of air temperature and relative humidity under optimum (October 2022–January 2023) and natural heat-stress (April–July 2023) conditions

Note: Heat stress was confirmed by mean maximum temperatures exceeding the optimum range (25-30^{0}C) for bottle gourd during reproductive stage.

humidity, and rainfall. During Rabi 2022–23 (non-stress), mean maximum and minimum temperatures were 29.66 °C and 17.61 °C, respectively, with an average relative humidity of 78.80% and total rainfall of 32.33 mm. In Kharif-1 2023 (heat stress), mean maximum temperature increased by 4.96 °C (34.62 °C) and mean minimum temperature increased by 6.75 °C (24.36 °C) compared to non-stress conditions, while relative humidity decreased by 4.45% and rainfall increased by 132.17 mm. Temperatures above 30 °C during Kharif-1 adversely affected flowering and fruit set, confirming effective heat stress conditions for the experiment (Figure 3.1).

3.2.1.3 Experimental design

All fifty-eight bottle gourd genotypes were evaluated using Randomized Complete Block Design (RCBD). Each plot consisted of ten plants, with 2.5 m spacing between rows to rows and 2.0 m plant to plant ensure optimal growth and minimize competition. At both experiments under optimum and natural heat-stressed field conditions were managed under uniform agronomic practices, including fertilization, irrigation, and pest management, with the exception of sowing dates, which were adjusted to impose the intended heat stress. This design allowed for reliable assessment of genotypic performance while controlling environmental variation.

3.2.1.4 Methods

Two independent experiments were undertaken to evaluate the studied genotypes, one under optimum (non-stress) conditions during the Rabi 2022–23 season and the other under natural heat stress conditions during the Kharif-1, 2023 (summer season). Both experiments were conducted at the BRAC Vegetable Research Center, Dinajpur. Under optimum (non-stress) conditions, seeds of 58 bottle gourd genotypes were sown in seedling trays on 16 October 2022 and transplanted in the field on 01 November 2022. In contrast, under natural heat stress conditions, seeds of the same genotypes were sown on 16 April 2023 and subsequently transplanted on 1 May 2023. Each replication consisted of a double row with 10 plants per accession. Plants were grown on bamboo and net trellises to facilitate proper vine training and fruit development.

3.2.1.5 Fertilizer application and intercultural operation

A basal dose of 5 kg well-decomposed cow dung, 60 g triple super phosphate (TSP), 20 g urea, 20 g muriate of potash (MoP), 20 g gypsum, 3 g zinc sulfate, 3 g borax, 3 g

magnesium sulfate, and 3 g carbofuran was applied in each pit at the time of transplanting. In addition, top dressing was carried out with 10 g urea and 10 g MoP per pit at 15-20 days after transplanting, followed by irrigation. A total of four top dressings were applied at equal intervals in the same manner. Standard cultural practices, including weeding, mulching, pruning, and training, along with recommended plant protection measures, were adopted to ensure optimal growth and development of the crop. With the exception of sowing time, every other aspect of the two trials (agronomic package and practices) was similar.

3.2.1.6 Data collection

Various morpho-physiological data were collected from ten randomly selected plants of each genotype under both stressed and non-stressed conditions. For this purpose, ten representative plants were tagged in each unit plot during the growth stage, and observations were recorded individually for each plant. The mean values obtained from the ten plants per plot were subsequently used for statistical analysis. The parameters recorded are outlined below:

3.2.1.6.1 Days to first female flower appearance

The number of days from sowing to the opening of the first female flower of the plants was recorded.

3.2.1.6.2 Node of first female flower appearance

The number of nodes from the cotyledonary leaves to the node bearing the first female flower was recorded.

3.2.1.6.3 Days to first edible fruit harvest

The number of days from sowing to the harvest of the first marketable fruit was recorded. Marketable maturity was determined based on changes in fruit color, skin softness, and surface texture, as judged by experience.

3.2.1.6.4 Number of primary branches

The number of primary branches per plant was recorded by counting all branches emerging directly from the main stem. Observations were taken at the vegetative stage once branching was fully expressed.

3.2.1.6.5 Internode length (cm)

Internode length was measured as the distance between two successive nodes along the main vine. Measurements were taken using a measuring scale from the base upward on fully elongated vines. The mean internode length was expressed in centimeters (cm).

3.2.1.6.6 Fruit length (cm)

The length of fruits (cm) was measured from the stalk end to the blossom end at the edible maturity stage using a measuring scale.

3.2.1.6.7 Fruit diameter (cm)

Fruit diameter (cm) was measured at the middle portion of the fruit using a slide caliper.

3.2.1.6.8 Fruit weight (kg)

All harvested fruits were weighed, and the average fruit weight was calculated by dividing the total fruit weight by the number of harvested fruits.

3.2.1.6.9 Number of fruits per plant

The number of fruits harvested per plant was recorded from all successive pickings, and the cumulative total was expressed as fruits per plant.

3.2.1.6.10 Yield per plant (kg)

The total fruit yield per plant was computed by summing the weights of all fruits harvested from each plant and dividing by the number of plants, expressed in kilograms per plant.

3.2.1.6.11 Total soluble solid (%Brix)

Total soluble solids (TSS) were recorded using a calibrated digital refractometer. Clear juice extracted from the fruit was placed on the prism, and readings were taken at room temperature with automatic temperature compensation and expressed as °Brix according to the AOAC refractometric method (Latimer, 2023a).

3.2.1.6.12 Dry matter content

Dry matter was determined by oven-drying a known amount of fresh sample at 105 °C until constant weight was achieved. The dried sample was weighed, and dry matter percentage was calculated based on the ratio of dry weight to fresh weight and expressed as percentage (%) according to the AOAC method (Latimer, 2023b, Ranganna, 1986).

3.2.1.6.13 Ascorbic acid (Vitamin C)

Ascorbic acid content was measured using the standard DCPIP titration method. Fresh bottle gourd pulp was extracted with 3% metaphosphoric acid, filtered, and titrated against

standardized DCPIP to determine vitamin C concentration. Results were expressed as mg ascorbic acid per 100 g fresh weight (Latimer, 2023c, Ranganna, 1986).

3.2.1.7 Data analyses

The data generated in the present investigation were statistically analyzed using appropriate biometric techniques. Mean values for each trait were computed and subjected to univariate, bivariate, and multivariate analyses. Descriptive statistics such as mean, range, and standard deviation were estimated, and the analysis of variance (ANOVA) for each trait was performed using Statistix 10.0. The ANOVA corresponding to the experimental design was carried out to partition the total variation into treatment and replication effects, following the standard procedures outlined by Panse and Sukhatme (1967).

Table 3.3: Expected Analysis of variance table

Sources of Variation	Degree of Freedom	Sum of squares	Mean sum of Squares	'F' values	
				Calculated	Tabulated
Replications	r-1	RSS	RMS	RMS/EMS	
Treatments	t-1	TrSS	TrMS	TrMS/EMS *****Significant at 5% ******Significant at 1%	
Error	(r 1) (t -1)	ErSS	EMS		

Where,

R = number of replications

T = number of treatments (genotypes, including parents)

RSS = Sum of square due to replications

TrSS = Sum of square due to treatment

ErSS = Sum of square due to error

TrMS = Mean sum of square due to treatments (Genotypes)

EMS = Mean sum of square due to error

3.2.1.7.1 Estimation of mean, range and coefficient of variations

Mean

The mean of the character was estimated by summing up all the observations and dividing the sum by the number of observations.

$$\overline{X} = \frac{\sum xi}{n}$$

Where,

ΣXi = Summation of all the observation,

n = Number of observations

Range

Range is the difference between the last and greatest terms of a series of observations and thus provides the information about the variability present in the genotype.

Critical difference

CD = SEd x t Value at 5% at error degree of freedom

$$SEd = \sqrt{\frac{2EMS}{r}}$$

Where,

SEd = Standard error of difference between two treatment means

EMS = Error Mean of square

r = Number of replications

Standard error of mean

$$SEm\pm = \sqrt{\frac{EMS}{r}}$$

Coefficient of variation (%)

Standard deviation expressed as a percentage of the mean is known as coefficient of variation (CV). It was calculated as:

$$CV\% = \frac{SD}{\overline{X}} \times 100$$

Where,

$\overline{X}$ = mean of character

SD = standard deviation

3.2.1.7.2 Estimation of genotypic and phenotypic variances

Genotypic and phenotypic variances were estimated according to the formula given by Johnson *et al.* (1955).

Genotypic variance (σ^2 g) = (GMS-EMS)/r

Where,

GMS = Mean square of variety

EMS = Mean square of error

r = Number of replications

The phenotypic variance (σ^2 p) can be calculated by adding genotypic variance (σ^2 g) with error variance (σ^2 e), as in the following formula:

Phenotypic variance (σ^2 p) = Genotypic variance (σ^2 g) + Error variance (σ^2 e)

Where, Error variance (σ^2 e) = Error mean square (EMS)

3.2.1.7.3 Estimation of genotypic and phenotypic coefficients of variation

The genotypic and phenotypic coefficients of variation were calculated according to the formula suggested by Burton (1952).

Genotypic coefficient of variation (GCV) = ($\sqrt{\ }\sigma^2$ g) X 100/Mean

Where,

σ^2 g = Genotypic variance

Mean = Population mean

Similarly,

Phenotypic co-efficient of variation (PCV) = ($\sqrt{\ }\sigma^2$ p) X 100/Mean

Where,

σ^2 p = Phenotypic variance

Mean = Population mean

3.2.1.7.4 Estimation of heritability and genetic advance

Heritability in a broad sense was estimated by the following formula suggested by Johnson *et al.* (1955).

Heritability in broad sense h^2b (%) = (σ^2 g X 100) / σ^2 p

Where,

σ^2 g = Genotypic variance

σ^2 p = Phenotypic variance

The expected genetic advance and genetic advance in percent of mean were calculated according to the formula used by Allard (1960) and Comstock and Robinson (1952).

Genetic advance (GA) = h^2_b.K. σp

Where,

h^2_b = Heritability in broad sense

K = Selection differential, 2.06 at 5% selection intensity

Genetic advance in percent of mean was calculated from the formula given below.

Genetic advance in percent of mean, GA (%) = (GA X 100)/Mean

Where, mean = Population mean

3.2.1.8 Estimation of phenotypic and genotypic correlations

Relationships between yield and yield-associated characters (thirteen) were studied at genotypic and phenotypic levels. Genotypic and phenotypic correlation coefficients between characters contributing to yield were estimated following the formula suggested by Miller *et al.* (1958).

Genotypic correlation

$$r_{g_{1.2}} = \frac{\text{Cov.}_{g_{1.2}}}{\sqrt{V_{g_1} \text{ x } V_{g_2}}}$$

Where,

$Cov.g_{1.2}$ = Genotypic covariance between the variables X_1 and X_2

Vg_1 = Genotypic variance of the variable X_1

Vg_2 = Genotypic variance of the variable X_2

Similarly, Phenotypic correlation,

$$r_{ph_{1.2}} = \frac{\text{Cov.}_{ph_{1.2}}}{\sqrt{V_{ph_1} \text{ x } V_{ph_2}}}$$

Where,

$Cov.ph_{1.2}$ = Phenotypic covariance between the variables X_1 and X_2

Vph_1 = Phenotypic variance of the variable X_1

Vph_2 = Phenotypic variance of the variable X_2

The significance of the correlation coefficient (r) was tested by comparing the calculated value of "r" with the tabulated value at (n − 2) degrees of freedom.

When the calculated "r" exceeded the tabulated value at a given probability level, the correlation was considered statistically significant.

In cases where the tabulated value of "r" was not available, the significance of the correlation coefficient was tested using the calculated *t*-value.

$$t = r\sqrt{(n-2/1-r2)}$$

If the calculated *t*-value exceeds the tabulated *t*-value at (n − 2) degrees of freedom and at the specified probability level, the corresponding correlation coefficient considered statistically significant.

3.2.1.9 Estimation of path coefficients

The genotypic correlation coefficients were further partitioned into direct and indirect effects through path coefficient analysis as proposed by Wright (1921) and later modified by Dewey and Lu (1959). Path coefficient analysis represents a standardized partial regression technique that partitions the correlation coefficient into components measuring both direct effects of one variable on another and indirect effects mediated through other related variables.

The cause and effect relationship between yield and its component traits was assessed using path coefficient analysis. The path coefficients for yield-associated characters were derived separately from phenotypic and genotypic correlation matrices following the procedure of Singh and Chaudhary (1985) and Dabholkar (1992), originally developed by Wright (1921). Dewey and Lu (1959) was first applied this method in plant sciences to partition the direct and indirect effects of contributing characters on yield in crested wheatgrass. In the present study, twelve yield-contributing traits were considered as independent variables (X_1, X_2 … X_{12}), while yield was treated as the dependent variable (X_s). The path coefficients were estimated by solving a set of simultaneous equations of the following general form:

r_{1S} = P_{1S} + r_{12} P_{2S} + r_{13} P_{3S} + r_{14} P_{4S} + r_{15} P_{5S} + r_{16} P_{6S} + r_{17} P_{7S} + r_{18} P_{8S}+ r_{19} P_{9S}+ r_{110} P_{10S}+ r_{111} P_{11S}+ r_{112} P_{12S}

r_{12S} = r_{101} P_{1S}+ r_{102} P_{2S}+ r_{103} P_{3S} + r_{104} P_{4S} + $r_{105}P_{5S}$ + r_{106} P_{6S} + r_{107} P_{7S} + $r_{108}P_{8S}$ + r_{109} P_{9S} + r_{118} P_{10S} + r_{111} P_{11S} +P_{12S}

Where,

P_{1S}, P_{2S}… P_{12S} = path coefficients of the variables X_1, X_2,… X_{12} on X_S, respectively

r_{1S}, r_{2S} …… r_{12S} = Correlation coefficients of variables X_1, X2, … X12 with X_S respectively

The residual effect (R), i.e., the variation unaccounted for by the component characters, which were not studied, was estimated using the formula as follows:

$$\text{Residual effect, } R = [1 - (r_{1S} P_{1S} + r_{2S} P_{2S} + \ldots + r_{11S} P_{11S} + r_{12S} P_{12S})]^{½}$$

A direct and indirect effect of different characters on fruit yield was calculated at the genotypic level.

3.2.2 Experiment-II: Screening and Identification of Heat-Tolerant Bottle Gourd Genotypes Using Stress Tolerance Indices

3.2.2.1 Experimental materials

Fifty-eight bottle gourd inbred lines were collected from Bangladesh's AEZs, national and international sources, including AVRDC and seed companies from India, China, and Thailand. All the evaluated genotypes were selfed for several generations at BARDC and Vegetable Research Center, Dinajpur, BRAC Seed and Agro Enterprise to ensure homozygosity and evaluated under both heat-stressed and non-stressed conditions. Their key morphological traits and images are presented in Table 3.2 and Plate 3.1.

3.2.2.2 Weather data and heat status during the experimental period

The monthly weather data (Figure 3.2) clearly distinguish the optimum (Rabi) and heat-stress (Kharif-1) field environments for the experiment. During the Rabi 2022–23 season, plants grew under favorable, non-stress conditions with moderate temperatures (average maximum/minimum 29.66/17.61 °C), high relative humidity (78.80%), and very low rainfall, which together ensured normal vegetative growth, timely flowering, and unhindered fruit set. In contrast, the Kharif-1 2023 season imposed a distinctly stressed environment, where temperatures rise sharply to an average max/min of 34.62/24.36 °C, representing increases of 4.96 °C and 6.75 °C over the optimum season. These weather data highlight a clear contrast between the two field environments. These elevated temperatures exceeded the critical threshold of 30 °C during most of the crop cycle, particularly around flowering, a stage highly sensitive to thermal stress. Moreover, relative humidity dropped by 4.45%, and rainfall increased by 132.17 mm, creating additional physiological stress and fluctuating moisture conditions. These sustained high-temperature conditions effectively induced field-based natural heat stress for reliable genotype evaluation.

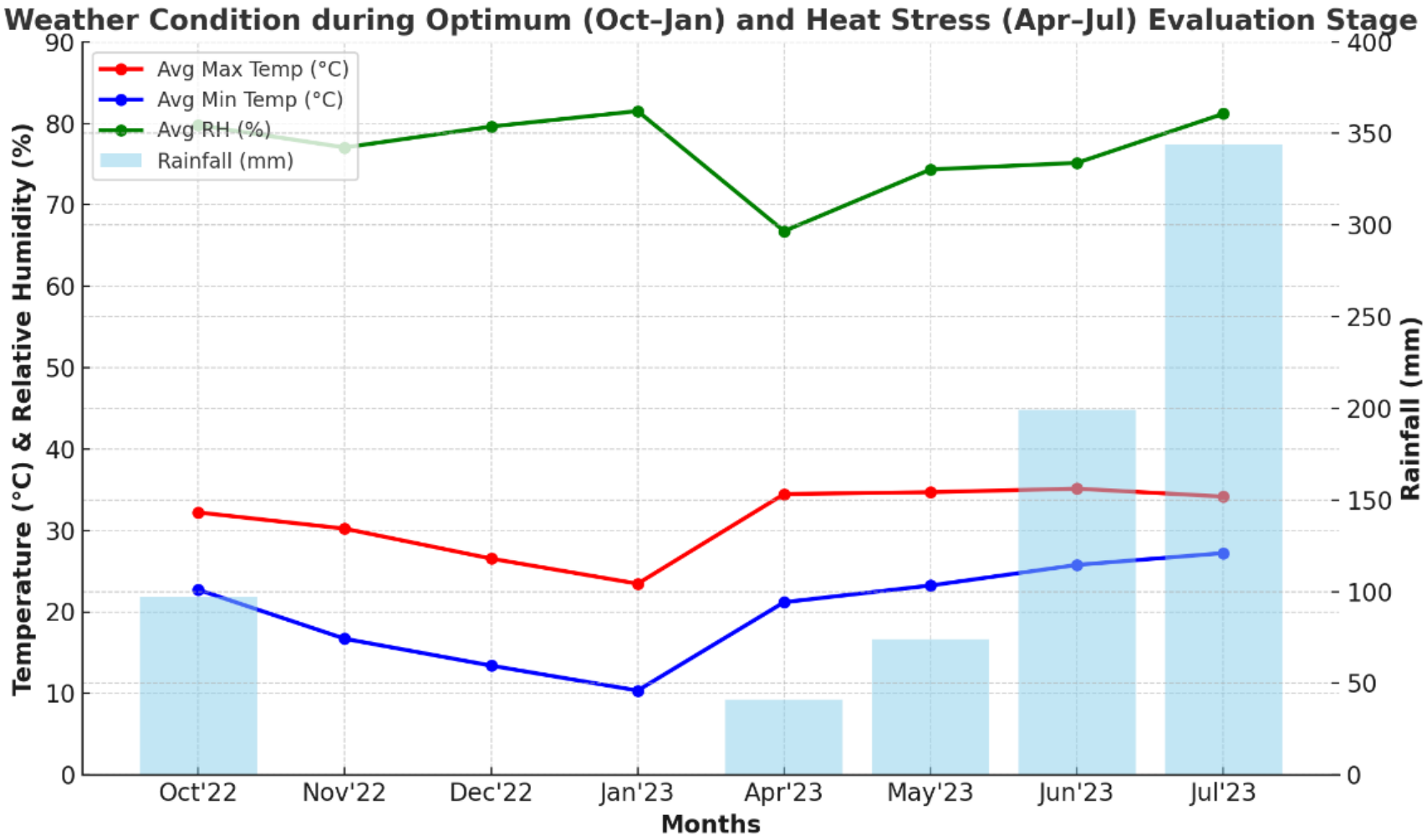


Figure 3.2 Weather condition during Optimum and Heat stress experimental period

3.2.2.3 Data collection

Key yield components like fruit diameter, number of fruits per plant, fruit weight and yield from the findings from path coefficient analysis were assessed for this study. A variety of genotypes, ranging from two to twelve times were picked before the plants stopped producing tender edible fruits under both heat stressed and optimum conditions. Fruit yield (kg) was converted into tons per hectare (t ha^{-1}). The morphological data were collected following 3.2.1.6.

3.2.2.4 Statistical analyses

MS Excel 2016 was utilized for data entry and processing, phenology duration and descriptive analysis, percent yield reduction (PYR), and stress index calculation. The stress indices, PCA analysis, and biplot were analyzed using Plant Abiotic Stress Index Calculator (iPASTIC) (Pour-Aboughadareh *et al.*, 2019).

Correlation and significance tests were performed in Python OPStat, and cluster dendrograms were generated using the Agricolae tool in R (version 3.4.2). The study used the least significant difference (LSD) test to compare landraces, computed coefficients of variation (CVs), and analyzed yield and stress indices. The significance of correlation coefficients was assessed using the Student's t-test (Snedecor & Cochran 1989).

3.2.2.5 Estimation of heat stress tolerance indices

Various heat stress indices, viz., tolerance index (TOL), mean productivity (MP), geometric mean productivity (GMP), stress susceptibility index (SSI), stress tolerance index (STI), yield index (YI), and yield stability index (YSI), were calculated to measure heat tolerance or susceptibility of the test genotypes using inter-relationships of various indices employing yield data under heat-stressed and non-stressed conditions.

To evaluate heat tolerance in genotypes, several indices were calculated to assess yield performance under heat stress and non-stress conditions. The Stress Susceptibility Index (SSI) measures the relative sensitivity of a genotype to heat stress; genotypes with SSI < 1 are considered tolerant. The Stress Tolerance Index (STI) identifies genotypes with superior yield under both stress and non-stress conditions, with higher values indicating broader adaptability. Geometric Mean Productivity (GMP) and Mean Productivity (MP) reflect overall yield stability, where higher values denote consistent performance across

environments. The Tolerance Index (TOL) quantifies absolute yield loss due to heat stress, whereas the Percentage Yield Reduction (PYR) expresses this reduction as a proportion of potential yield; lower values for both indices indicate greater stability. The Harmonic Mean (HM) gives more weight to lower yields, favoring genotypes that maintain productivity under stress. The Yield Index (YI) and Yield Stability Index (YSI) measure relative and proportional yield performance under stress, respectively, with higher values indicating superior adaptability and stability.

The heat stress and non-stressed conditions yield data from the paired trials that were used in place of the genotypic mean values for yield under stress (Ys) and potential yield under non-stress (Yp) variables, respectively, in the equations for the above indices. Xs and Xp are the mean yields of all genotypes per trial under stress and non-stress conditions (Porch 2006).

The following calculations were used to compute heat tolerance indices:

Tolerance index (TOL) = Yp-Ys (Rosielle and Hamblin, 1981)

Mean productivity (MP) = $\frac{(Yp+Ys)}{2}$ (Rosielle and Hamblin, 1981)

Harmonic mean (HARM) = 2($\frac{(Ys \times Yp)}{(Ys+Yp)}$ (Bidinger *et al.*, 1987)

Geometric mean productivity (GMP) = $\sqrt{(Yp \times Ys)}$ (Fernandez 1992; Ramirez and Kelly, 1998)

Stress susceptibility index (SSI) = $\frac{1-(Ys/Yp)}{(1-(Xs/Xp)}$ (Fischer and Maurer, 1978)

Stress tolerance index (STI) = $\frac{(Ys \times Yp)}{(Xp)2}$ (Fernandez 1992)

Yield index (YI) = Ys/Xs (Gavuzzi *et al.*, 1997)

Yield stability index (YSI) = Ys/Yp (Bouslama and Schapaugh, 1984)

Relative stress index (RSI) = (Ys / Yp) / (Xs / Xp) (Fischer and Wood, 1979)

Percent yield reduction (PYR) = (Yp − Ys)/Yp × 100 (Farshadfar and Javadinia, 2011)

3.2.2.6 Ranking of bottle gourd genotypes for heat tolerance

To identify the most desirable heat-tolerant cultivar, the mean rank and the standard deviation of ranks across all drought tolerance indices were calculated, and based on these parameters, the superior heat-tolerant cultivars were determined.

Table 3.4: Yield-based indices used for evaluating Heat tolerance of bottle gourd genotypes

Heat Stress Indices	Formulae	References	Correlation with stress/yield
Tolerance index (TOL)	Yp-Ys	Rosielle and Hamblin, 1981	Negatively correlated genotypes with lower TOL indicating higher heat tolerance.
Mean productivity (MP)	$\frac{(Yp + Ys)}{2}$	Rosielle and Hamblin, 1981	Positive values are highly stress tolerant. Genotypes having positive correlation with yield and MP said to be highly stress tolerant.
Geometric mean productivity (GMP)	$\sqrt{(Yp \times Ys)}$	Ramirez and Kelly, 1998	Genotypes with a high GMP value said to be more heat stress tolerant.
Harmonic Mean (HARM)	$2(\frac{(Ys \times Yp)}{(Ys + Yp)}$	Bidinger *et al.,* 1987	Higher HARM in genotypes, greater heat tolerance.
Stress susceptibility index (SSI)	$\frac{1 - (Ys/Yp)}{(1 - (Xs/Xp)}$	Fischer and Maurer, 1978	Negatively correlated with heat stress. Genotypes highly stress tolerant, moderately tolerant and intolerant when SSI < 0.5, 0.5-1.0, and > 1.0, respectively.
Stress tolerance index (STI)	$\frac{(Ys \times Yp)}{(Xp)2}$	Fernandez, 1992	Positively correlated with yield under stress.
Yield index (YI)	Ys/ Xs	Gavuzzi *et al.,* 1997	Positive correlation with heat stress and yield
Yield stability index (YSI)	Ys/Yp	Bouslama and Schapaugh, 1984	Negatively correlated with TOL and SSI. higher YSI indicated more stress-tolerant genotypes having higher YSI, more tolerant to stress.
Relative stress index (RSI)	(Ys / Yp) / (Xs / Xp)	Fischer and Wood, 1979	RSI < 1 susceptibility, RSI > 1 suggests more tolerant
Percent yield Reduction (PYR)	$(Yp - Ys)/Yp \times 100$	Farshadfar and Javadinia, 2011	Negatively correlated with heat stress, higher yield reduction indicated stress susceptibility

For screening heat-tolerant genotypes, the rank sum (RS) was calculated following the method of Farshadfar and Elyasi (2012), using the formula:

$$RS = \bar{R} + SDR$$

Where,

$\bar{R}$ = Mean rank of a genotype across all heat tolerance indicators

SDR = Standard deviation of ranks

The standard deviation of ranks (SDR) was computed as:

$$SDR = \sqrt{S^2 i} = \sum_{i=1}^{n} \frac{(Rij - \bar{R}i)2}{n-1}$$

Where

Rij=Rank of the ith genotype for the jth heat tolerance indicator

Ri=Mean rank of ith genotype across all indicators

n = Total number of tolerance indicators considered

3.2.2.7 Cluster diagram

Cluster analysis was carried out using heat stress tolerance indices data in Python (Ward's method with Euclidean distance). Genotypes were grouped into similarity-based clusters and subsequently categorized as heat tolerant, moderately tolerant, or susceptible based on their respective cluster means under stress tolerance indices. Genotypes grouped in clusters with higher mean yield and favorable physiological/fruit attributes were classified as tolerant; those with intermediate mean values as moderately tolerant; while clusters showing poor performance were considered susceptible.

3.2.3 Experiment-III: Selection of Heat-Tolerant Inbred Lines Based on Combining Ability Using Line × Tester Analysis in Bottle Gourd

3.2.3.1 Experimental materials

A total of twenty-two (22) bottle gourd genotypes were selected for a Line × Tester (L×T) mating design, based on their heat tolerance identified from a preliminary screening of fifty-eight (58) genotypes in Experiment 1 and II. Among these, two medium heat-tolerant with two diveresd types genotypes BG-03 and BG-58 were considered as testers, while twenty highly tolerant genotypes were selected as lines.

3.2.3.2 Performing line × tester crossing and hybrid development

During the Rabi season of 2023-24, seeds of the two testers (pollen parents) and twenty lines (seed parents) were sown simultaneously on October 1, 2023, to ensure synchronized flowering and facilitate hybridization. Seedlings were raised in polybags, and 20-day-old plants were transplanted into the field on October 20, 2023. Each experimental plot measured 20 m² (10 × 2 m), with a spacing of 2 m between rows and 1 m between plants to accommodate vine growth and development. The experiment was conducted using a single crossing block setup. All recommended horticultural practices were followed, as per the guidelines of the Bangladesh Agricultural Research Institute (Akhond *et al.*, 2025).

To ensure genetic purity and avoid cross-contamination during hybridization, pistillate flower buds of the female parents were bagged between 8:00 and 11:00 a.m. prior to anthesis. Given the monoecious nature of bottle gourd, emasculation was unnecessary. In the same afternoon (between 3:00 and 5:00 p.m.), pollen grains were collected from freshly opened, pre-bagged staminate flowers of the designated male parents and manually applied to the stigmas of the bagged female flowers. Following pollination, the pistillate flowers were immediately re-bagged for two to three days to prevent contamination and were labeled for identification.

Each of the twenty lines was crossed with the two testers following the Line × Tester mating design as described by Kempthorne (1957), resulting in 40 F_1 hybrids. The crossed fruits were left on the vine to mature and dry naturally. After harvesting, fruits were cured for 10 to 15 days to ensure complete physiological seed development. Seeds were then extracted from tagged fruits, cleaned, and initially shade-dried by hanging in mesh bags for one day. Further drying was carried out by spreading the seeds in nylon bags on tarpaulin sheets (avoiding direct soil contact) for two hours each morning over five consecutive days, reducing the moisture content to approximately 8%. Once adequately dried, seeds were treated and stored in cold storage to prevent infestation and later deposited in the genebank.

3.2.3.3 Experimental design and field establishment

Field evaluation of 40 F_1 hybrids along with 22 parental lines (20 lines and 2 testers) was conducted during the Kharif-1 season of 2024 using a replicated alpha-lattice design to minimize experimental error and improve precision. The 62 genotypes were arranged in

two replications, each comprising 7 incomplete blocks with 9 plots per block. Genotype randomization was performed using PBTools (IRRI, 2014). Each 20 m² plot (10 × 2 m) accommodated 10 plants, with 2 m row spacing and 1 m plant spacing to support optimal vine growth and development.

Seeds of all entries were sown in seedling trays on April 16, 2024. The potting medium was composed of coconut coir, ash, and decomposed cow dung in a 50:25:25 ratio to ensure proper aeration and nutrient availability. After 20 days, when the seedlings had developed 3 to 4 true leaves, they were transplanted to the field on May 5, 2024. Depending on the rainfall, the field was irrigated at regular intervals, and recommended standard cultural and agronomic practices were followed to raise a healthy crop.

3.2.3.4 Fertilizer management practices

The following fertilizer was applied in the bottle gourd field during the evaluation period: During land preparation, 50% of the total required cow dung, triple superphosphate (TSP), and muriate of potash (MOP) were applied along with the full doses of zinc sulphate, boric acid, and magnesium sulphate (Table 3.5). The remaining 50% of cow dung and TSP was applied seven days before transplanting the seedlings. Urea was top-dressed in three equal splits at 20, 50 and 75 days after transplanting, while the remaining portion of MOP was also applied in two equal splits at 35 and 55 days after transplanting. Gypsum was fully applied during land preparation. Bottom of Form Top dressing of urea and MOP was done by placing fertilizers in four equal splits, each applied at a depth of 10–15 cm within the plant basin and incorporated into soil to ensure efficient nutrient uptake and minimize losses.

3.2.3.5 Weather conditions during the experimental period

During the hybridization stage (October 2023 to February 2024), the field conditions remained mild and favorable for crop growth (Figure 3.3). The average maximum temperature ranged from 21.41°C to 31.85°C, with a mean of 27.6°C (Figure 3.3), while the minimum temperature varied between 10.18°C and 21.66°C (mean 15.7°C). Relative humidity was generally high (73.9–86.8%), peaking in January, whereas sunshine duration averaged 5.9 hrs per day, with the lowest in January (1.97 hrs). Evaporation rates were low (1.76–3.31 mm), and total rainfall during this stage was 230 mm, largely confined to October (Appendix II). These conditions ensured a favourable environment for hybridization and seed setting without heat stress interference.

Table 3.5: Fertilizer Application Schedule for Bottle Gourd Cultivation during the Experimental Period

Name of Fertilizer	Total Amount	During land preparation	20 DAT	50 DAT	75 DAT
Cowdung	10,000 kg	10,000 kg	–	–	–
Urea	200 kg	–	50 kg	75 kg	75 kg
TSP	150 kg	150 kg	–	–	–
MOP	120 kg	60 kg	–	30 kg	30 kg
Gypsum	100 kg	100 kg	–	–	–
Zinc	10 kg	10 kg	–	–	–
Boric Acid	2 kg	2 kg	–	–	–
Magnesium Sulphate	20 kg	20 kg	–	–	–

DAT: Days after transplanting

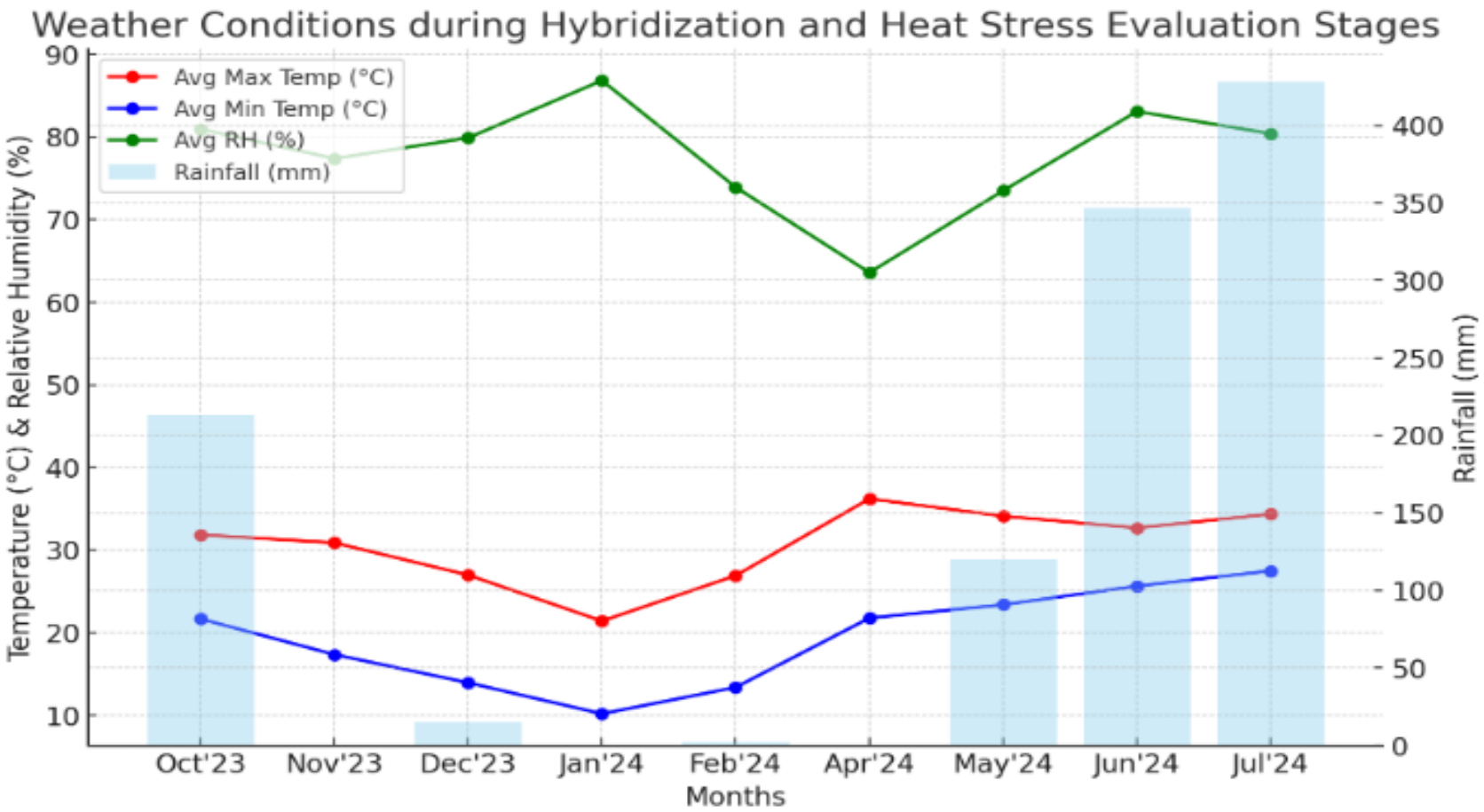


Figure 3.3. Weather conditions during hybridization and F_1 evaluation stage

The evaluation stage under heat stress (April to July 2024) was characterized by markedly higher temperatures and variable humidity. The maximum temperature ranged from 32.67°C to 36.20°C (mean 34.3°C), while the minimum temperature rose from 21.77°C in April to 27.48°C in July (mean 24.6°C), reflecting persistently warm nights (Figure 3.3). April was the driest and hottest month, with the lowest humidity (63.6%), longest sunshine (8.67 hrs), and highest evaporation (4.72 mm), imposing severe dry heat stress. With the onset of monsoon, relative humidity increased to 83.1% in June and 80.4% in July, accompanied by heavy rainfall totaling 895 mm (Appendix II). Despite reduced sunshine (3.4–5.4 hrs) during June–July, the combination of high temperature, high humidity, and excessive rainfall created a compounded stress environment. These contrasting conditions provided clear differentiation between non-stress and stress environments for evaluating bottle gourd genotype.

3.2.3.6 Data collection

Ten randomly chosen plants in each replication of all the entries were labelled and used for recording the observations. The observations were recorded on ten randomly selected plants from parents and crosses from each unit plot to collect data during the vegetative stage. The chosen plants were marked, and data was collected for the following characteristics for each plant and plot. The mean of ten plants was taken for statistical analysis. The parameters employed in collecting data of days to first female flower appearance, days to first fruit harvest, fruit length (cm), fruit diameter (cm), average fruit weight (kg), number of fruits per plant, and fruit yield per plant were previously outlined in the section 3.2.1.6.

3.2.3.7 Data analyses

3.2.3.7.1 Analysis of variance

The collected data were subjected to statistical analysis using the line × tester method as described by Kempthorne (1957). The effects of general combining ability (GCA) and specific combining ability (SCA) were estimated through partitioning of variance components.

A. Total sum of squares (treatments):

$$\text{SS (treatments)} = \frac{\sum\sum C^2 ij + \sum\sum P^2 ii}{r} - \text{CF (Overall)}$$

Where,

Cij = Observation of the i × j crosses.

Pii = Observation of the ith parent.

r = number of replications

B. Crosses sum of squares:

$$SS\ (crosses) = \frac{\sum\sum C^2 ij}{r} - CF\ (crosses)$$

C. Parents sum of squares:

$$SS\ (parents) = \frac{\sum\sum P^2 ii}{r} - CF\ (parents)$$

D. Parents vs. crosses:

SS (parents vs. crosses) = SS treatment-SS (crosses)-SS (parents)

= CF (crosses) + CF (parents) - CF (overall)

Correction factors

E. For crosses:

$$CF\ (Crosses) = \frac{[Grand\ total\ (Crosses)]^2}{[Total\ number\ of\ crosses \times number\ of\ replications]}$$

F. For parents

$$CF\ (Parent) = \frac{[Grand\ total\ (parent)]^2}{[Total\ number\ of\ parents \times number\ of\ replications]}$$

G. Overall correction factor:

$$CF\ (Overall) = \frac{(Grand\ total\ of\ all\ observations)^2}{(Total\ number\ of\ treatments \times r)}$$

3.2.3.7.2 Analysis of line × tester effects

The sums of squares (SS) due to lines, testers, and line × tester interaction were calculated using the following formulae:

$$SS\ (Lines) = \frac{\sum\sum L^2 ij}{r \times t} - CF\ (Crosses)$$

Where,

$\sum\sum L^2 ij$ = Sum of squares of line totals

r = Number of replications

t = Number of testers

$$SS\ (Testers) = \frac{\sum\sum T^2 ii}{r \times l} - CF\ (Crosses)$$

Where,

$\sum\sum T^2 ii$ = Sum of squares of tester totals

r = Number of replications

l = Number of lines

SS (Line × Tester) = SS (crosses) − SS (Lines) − SS (Testers)

3.2.3.7.3 Estimation of GCA effects

The general combining ability (GCA) effects for lines and testers were estimated using the following formulas:

GCA for lines:

$$gi = \frac{xi..}{tr} - \frac{x....}{ltr}$$

Where,

l = Number of lines

t = Number of testers

r = Number of replications

GCA for testers:

$$gi = \frac{x.j.}{lr} - \frac{x....}{ltr}$$

Where,

Xi. = Line total

X.j = Tester total

r = Number of Replications

l = Number of Lines

t = Number of Testers

3.2.3.7.4 Estimation of standard error (S.E.) for combining ability effects

The standard errors of GCA and SCA effects were calculated using the following formulas:

S.E. (GCA for line) = $\{M_e / (r \times t)\}^{1/2}$

S.E. (GCA for tester) = $\{M_e/(r \times l)\}^{1/2}$

S.E. (SCA for effects) = $\{M_e/r\}^{1/2}$

S.E. (gi-gj) for line = $\{2M_e / (r \times t)\}^{1/2}$

S.E. (gi-gj) for tester = $\{2M_e / (r \times l)\}^{½}$

Where

M_e = Error mean sum of squares

gi-gj = Difference between GCA effects of any two lines or tester pairs

3.2.3.7.5 Estimation of correlation between mean performance and GCA effects of parents

The correlation between mean performance and GCA effects of parents was estimated using the following formula:

$$r = \frac{\sum\left(x_i^2 y_i^2\right) - \frac{\left(\sum x_i y_i\right)^2}{n}}{\left[\left\{\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}\right\}\left\{\sum y_i^2 - \frac{\left(\sum y_i\right)^2}{n}\right\}\right]^{\frac{1}{2}}}$$

3.2.3.7.6 Significance test for correlation coefficient between mean and GCA effects of parents

The significance of the correlation coefficient (r) between mean performance and GCA effects of parents was tested using the paired Student's *t*-test:

$$t = \frac{r(n-2)^{\frac{1}{2}}}{(1-r^2)^{\frac{1}{2}}} \text{ with (n-2) df}$$

Where,

n = Number of paired observations

r = Correlation coefficient

3.2.4 Experiment-IV: Combining Ability and Heterosis Analysis of Selected Heat-Tolerant Genotypes in Bottle Gourd

3.2.4.1 Experimental materials

Six heat-tolerant and diverse inbred lines with good combining ability were selected from 22 lines and two testers using statistical tools, GCA effects, and ranking of lines and testers through line x tester analysis during the summer season (Kharif-1, 2024) under heat stress through findings of experiment no. 2. A 6 × 6 full diallel mating design was employed, resulting in 30 F_1 hybrids. Thus, the experimental materials comprised six parents and their 30 F_1 progenies.

3.2.4.2 Performing 6 × 6 diallel crosses and hybridization

A 6 × 6 full diallel crossing program was conducted at the BRAC Vegetable Research Center, Dinajpur, during the Rabi 2024–25 season. Six inbred lines selected from experiment-iii were used as parents for hybridization. Seeds were sown in seedling trays on October 1, 2024, and 14-day-old seedlings were transplanted into the field on October 15, 2024. Spacing was maintained at 2 m between rows, 1 m between plants, and 1 m between plots to facilitate normal vine growth. Plants were trained on bamboo and net trellises, and fertilizer and nutrient management were applied as described in Section 3.3.1 (Akhond *et al.*, 2025).

Controlled hybridization was performed following the full diallel mating design, which included selfs and reciprocals. The monoecious nature of the species, where separate male and female flowers exist on the same plant, eliminates the necessity for emasculation, thereby streamlining the crossing process. Pre-anthesis pistillate buds of female parents were bagged in the morning (07:00–10:00 h), and pollen was collected from freshly dehisced, pre-bagged staminate flowers of designated male parents. Pollination was carried out in the afternoon (15:00–17:00 h) during peak stigma receptivity and pollen viability. Pollinated flowers were tagged and rebagged for 48–72 hours to prevent foreign pollen contamination. Hybrid fruits were allowed to mature and dry on the vine before harvest. Seeds were extracted from healthy fruits, washed, sun-dried, and stored properly to ensure viability and protection against pests for subsequent genetic evaluation.

3.2.4.3 Experimental design and field establishment

The experiment was conducted in a Randomized Complete Block Design (RCBD) with three replications. Thirty hybrids, along with six parents, were sown in seedling trays on May 1, 2025, and 15-day-old seedlings were transplanted on May 16, 2025. A spacing of 2 m between rows and 2 m between plants was maintained to ensure optimal vine growth, with plants trained on bamboo and net trellises. Each replication consisted of a double row of 10 plants per accession. A basal dose of organic and inorganic fertilizers was applied per pit, consisting of 5 kg cow dung, 60 g triple super phosphate (TSP), 20 g urea, 20 g muriate of potash (MoP), 20 g gypsum, 3 g zinc sulphate, 3 g borax, 3 g magnesium sulphate, and 3 g carbofuran. Top dressing was carried out with 10 g urea and 10 g MoP per pit at 18–20 days after transplanting, followed by irrigation, with a total of four top dressings applied. Standard intercultural operations, including weeding, mulching, pruning, training, and protective sprays, were performed to ensure healthy crop growth and development.

3.2.4.4 Weather condition and heat status during experimental period

During the experimental period (October 2024-August 2025), bottle gourd was exposed to contrasting thermal conditions. Moderate temperatures prevailed from October 2024 to February 2025, representing non-stressful heat conditions. While a distinct natural heat-stress period occurred from April to May, with the highest average maximum temperature recorded in April (36.70 °C), accompanied by low relative humidity (63.57%) and absence of rainfall, intensifying thermal stress. The subsequent monsoon months (May–August) were characterized by high temperatures along with increased rainfall and humidity, providing a warm and humid environment for F_1 evaluation. From May to August, the onset of monsoon rainfall (220–445 mm) was accompanied by moderate to high temperatures (32.98–34.35 °C) and elevated relative humidity (80–84%), developed a warm and humid drastic environment for F_1 growth and evaluation (Figure 3.4).

3.2.4.5 Data collection

Data were recorded on days to first female flower appearance flowering, node at first female flower appearance, days to first edible fruit harvest, fruit length, fruit diameter, fruit weight, number of fruits per plant, and fruit yield per plant, total soluble solids (TSS), dry matter content and ascorbic acid content. For this purpose, ten randomly selected plants from each plot of every replication were sampled from the F_1 hybrids along with their parents, following the procedure described in Section 3.2.1.6.

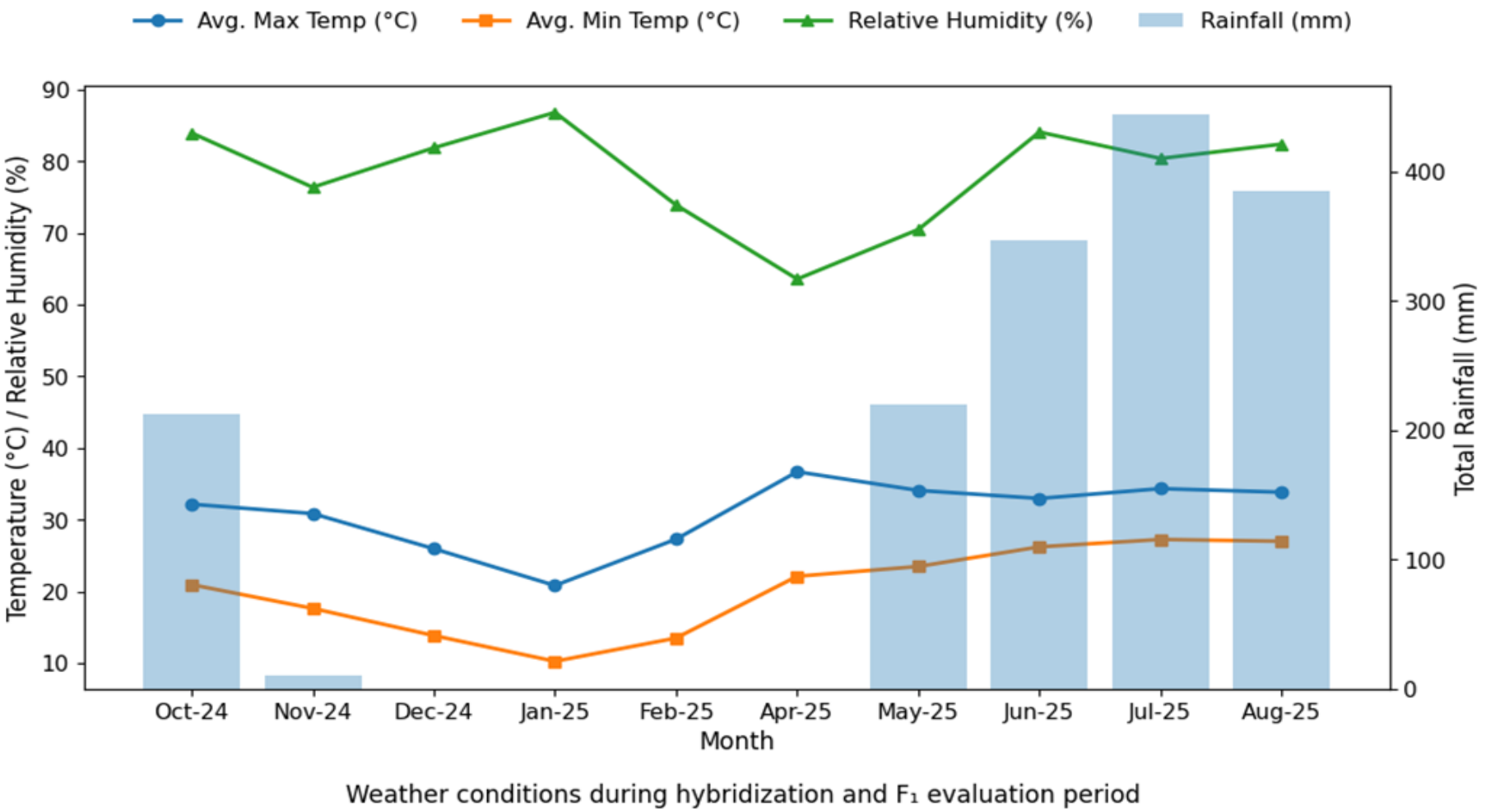


Figure 3.4. Weather conditions during hybridization (optimum) and F_1 evaluation (heat stress)

3.2.4.6 Data analyses

All data derived from the 6 × 6 diallel crosses (excluding reciprocals) on morpho-physiological traits were subjected to statistical analyses. Yield and yield-contributing characters were analyzed through biometrical approaches to partition variances attributable to combining ability, heterosis, and heritability (both broad and narrow sense). Combining ability and heterosis analyses were performed using Plant breeding tools (PBTools version 1.4) software (IRRI, 2014).

3.2.4.6.1 Analysis of combining ability

Combining ability analysis was performed using the diallel method of Griffing (1956a) under Method 1, Model 1 (fixed effects), involving six parents, 15 F_1s, and 15 reciprocal F_1s. The analysis partitioned the total variance into general combining ability (GCA) effects of parents and specific combining ability (SCA) effects of crosses. Variance components were further translated into genetic variances following Bulmer (1980), enabling the estimation of heritability in both the broad and narrow sense. This approach provided insights into the relative importance of additive and non-additive genetic effects, thereby facilitating the evaluation of parental potential and hybrid performance.

The mathematical model for the combining ability analysis is assumed to be:

$$Yij = \mu + gi + gj + sij + rij + \frac{1}{bc}\sum_{k}\sum_{l} e_{ijkl}$$

Where,

i,j. = 1, 2, …, p (p = number of parents involved in diallel)

k = 1, 2, ----------, r (r = number of replications)

l = 1, 2, ----------, c (c = number of observations per plot)

μ = Population mean

gi, gj = General combining ability (GCA) effects of the ith

gi, gj = General combining ability (GCA) effects of the jth parents,

Sij = Specific combining ability (SCA) effects for the cross between the ith and jth parents such that Sij = Sji.

rij = Reciprocal effects for the cross between ith and jth parents

eijkl = environmental effect associated with ijklth observation

The orthogonal partitioning of the variety sum of squares: ANOVA (Method 2, Model 1) with expectations of mean squares.

Table 3.6: Expected MS of combining ability

Sources	d.f.	Sum of Square	Mean Square	Expectations of mean Squares
GCA	p-1	Sg	Mg	$\sigma_e^2 + (p+2)\left[\frac{1}{p-1}\right]\sum_{x=1}^{p} g_i^2$
SCA	p(p-1)/2	Ss	Ms	$\sigma_e^2 + \frac{2}{p(p-1)}\sum_{i=1}^{p}\sum_{j=1}^{p} s_{ij}^2$
Error	(r-1) (t-1)	Se	Me	σ_e^2

Where,

P = number of parents

$$Sg = \frac{1}{p+2}\left[\sum_{i=1}(yi + yii)^2 - \frac{4}{p}y^2\right]$$

$$Ss = \sum_i \leq \sum_j {}^{y_{ij}^2} - \frac{1}{p+2}\sum_{i=1}{}^{(yi+yii)^2} + \frac{2}{(p+1)(P+2)}Y^2$$

Yi = total of the array involving the ith parent

Yii = mean value of the ith parent of the array

Yij = mean value of the ith × jth cross

Y.. = total of all the elements in the diallel table without reciprocals

$\left[\frac{P(p-1)}{2}\right]2progrmies$ and parental lines

Me = error mean square

The mean squares for GCA (Mg), SCA (Ms), and error (Me) were obtained by dividing each sum of squares by its corresponding degree of freedom. The significance of GCA and SCA effects was subsequently tested using appropriate F-ratios.

(i) The F-ratio for testing GCA was calculated as

$$F = \frac{M_g}{M_e}$$

The calculated F-value is compared with the tabulated F-value at (p−1) degrees of freedom for GCA versus the error degrees of freedom.

(ii) The F-ratio for testing GCA was calculated as

$$F = \frac{M_s}{M_e}$$

The calculated F-value was compared with the tabulated F-value at [P- (P-1)/2] degrees of freedom for SCA versus error degree of freedom.

3.2.4.6.2 Estimation of combining ability effects

When both MSg and MSs are significant, it validates the calculation of general combining ability (GCA, gi) for each parent and specific combining ability (SCA, Sij) for each cross. These effects were estimated using the following formulae:

(a) **Estimation of GCA effects**

$$g_i = \frac{1}{p+2}\left[\sum_{i=1}(y_i + y_{ii}) - \frac{2}{p}y\right]$$

(b**) Estimation of SCA effects**

$$S_{ij} = y_{ij}\frac{1}{(p+2)}(Y_i + Y_{ii} + Y_j + Y_{ij}) + \frac{2}{(p+1)(P+2)}Y$$

Where,

Yj = total of the array involving the jth parent

c) Standard errors

The standard errors, which are essential for evaluating the statistical significance of GCA and SCA effects and for comparing differences among GCA effects, were computed following established procedures.

(i) Standard error of combining ability effects

$$SE(g_i) = \left[\frac{P-1}{P(p-2)}\sigma_e^2\right]^{\frac{1}{2}}$$

$$SE(g_{ij}) = \left[\frac{P(P-1)}{(P+1)(p-2)}\sigma_e^2\right]^{\frac{1}{2}}$$

To test the significance of each g_i and S_{ij}, 't' values are calculated as follows:

For GCA effect

$$t(g_i) = \frac{g_i}{SE(g_i)}$$

For SCA effect

$$t(S_{ij}) = \frac{S_{ij}}{SE(S_{ij})}$$

The calculated 't'-value for each gi and Sij is tested against the table 't'-value at (P-1) and P (P-1)/2 degrees of freedom, respectively.

(ii) Standard error of the difference of combining ability effects

(a) Differences between GCA effects of parents

$$SE_d(g_i - g_j) = \left[\frac{2}{P+2}\sigma_e^2\right]^{\frac{1}{2}}$$

(b) Difference between SCA effects of two crosses, which include one common parent

$$SE_d(S_{ij} - S_{ik}) = \left[\frac{2(P+1)}{P+2}\sigma_e^2\right]^{\frac{1}{2}}$$

(c) Differences between SCA effects of two crosses, having no parent in common

$$SE_d(S_{ij} - S_{kl}) = \left[\frac{2P}{P+2}\sigma_e^2\right]^{\frac{1}{2}}$$

The critical difference of each pair of gi's and that of gij's was calculated as a product of the standard error and the 't' value for error degree of freedom at 5% and 1% levels of significance.

CD $(g_i\text{-}g_j)$ = SE_d $(g_i - g_j)$ x $t_{5\%}$ or $t_1\%$ at (P-1) d.f.

CD $(s_i\text{-}s_{ik})$ = SE_d $(s_{ij} - g_{ik})$ x $t_{5\%}$ or $t_{1\%}$ at [P (P-1)/2] d.f.

CD $(s_{ij}\text{-}s_{kl})$ = SE_d $(s_{ij}\text{-skl})$ x $t_{5\%}$ or $t_{1\%}$ at [P (P-1)/2] d.f.

3.2.4.7 Estimation of heterosis

Heterosis for each character was estimated by comparing the mean values of the 15 F_1 hybrids and their 15 reciprocal crosses with the better parent (BP) to calculate heterobeltiosis, with the mid-parent (MP) to calculate average heterosis, and with the check variety (CV) to calculate standard heterosis. Percent heterosis for each trait was calculated using the following formulae:

$$\text{Heterosis, H (\%)over mid parent (MP)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterosis, H (\%)over better parent (BP)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Heterosis, H (\%)over check variety (CV)} = \frac{\overline{F_1} - \overline{CV}}{\overline{CV}} \times 100$$

Where, $\overline{F_1}$, $\overline{MP}$, $\overline{BP}$ and $\overline{CV}$ are the mean of F_1, two parental populations, better parent and check variety respectively.

Significant differences of F_1 with MP, BP, and CV were tested using the t-test and calculated by the formula given below:

I. $[t] = \frac{\overline{F_1} - \overline{MP}}{\overline{SED}} \times 100$ Where, $SED = \sqrt{2EMS/r}$

II. $[t] = \frac{\overline{F_1} - \overline{BP}}{\overline{SED}} \times 100$ Where, $SED = \sqrt{2EMS/r}$

III. $[t] = \frac{\overline{F_1} - \overline{CV}}{\overline{SED}} \times 100$ Where, $SED = \sqrt{2EMS/r}$

Where, SED = Standard error of difference

EMS = Error means square and

r = Replication

CHAPTER IV
RESULTS AND DISCUSSION

This chapter presents the analysis, presentation, and interpretation of the results obtained from the present study. The experimental data were analyzed to identify desirable parents and superior cross combinations through the assessment of genetic variability, phenotypic and genotypic correlations, and path coefficient analysis. Genotypes were further evaluated for heat tolerance using stress tolerance indices to identify heat-tolerant genotypes, while combining ability was assessed through line × tester and diallel analyses. In addition, heterosis for phenological traits, yield and yield components, and quality attributes of bottle gourd under heat stress conditions was estimated using 6 × 6 diallel crosses. The results are presented under the following headings:

4.1 Study of genetic variability, correlation and path coefficient analysis under optimum and heat stress conditions

4.2 Screening and identification of heat-tolerant bottle gourd genotypes using stress tolerance indices

4.3 Selection of heat-tolerant inbred lines based on combining ability using line × tester analysis in bottle gourd

4.4 Combining ability and heterosis analysis of selected heat-tolerant genotypes in bottle gourd

4.1 Experiment-I: Study of Genetic Variability, Correlation and Path Coefficient Analysis under Optimum and Heat Stress Conditions

4.1.1 Analysis of variance (ANOVA) for yield and yield-contributing traits

The analysis of variance (Table 4.1.1) showed that genotypic differences were highly significant ($p < 0.01$) for all yield and yield-contributing traits under both optimum and heat stress conditions, indicating the presence of considerable genetic variability among the evaluated bottle gourd genotypes. This suggested ample scope for effective selection and improvement of yield-related traits in both environments.

Under optimum conditions, mean sum of squares due to genotypes were recorded and significant genotypic effects for days to first female flower appearance, node at first female flower appearance, days to first edible fruit harvest, internode length, number of

primary branches, fruit length, fruit diameter, number of fruits per plant, fruit weight, yield per plant, dry matter content (mg/100g), total soluble solids (TSS), ascorbic acid content (mg/100g) and yield per hectare. Similarly, under heat stress, all traits exhibited highly significant genotype effects, indicated that characters expression also strongly genotype dependent even under elevated temperature conditions. Replication effects were mostly non-significant across environments, and relatively low error mean squares indicated good experimental precision. The significant genotypic variation across environments demonstrated that the evaluated bottle gourd genotypes possess diverse genetic potential, and the expression of yield and its components was highly influenced by genotype even under heat stress conditions. This variability was essential for identifying heat-tolerant and high-yielding genotypes suitable for cultivation under rising temperature conditions.

4.1.2 Study of genetic variability under optimum and heat stress environments

Days to first female flower appearance

Substantial variability was observed among the bottle gourd genotypes both at optimum and heat stress conditions (Table 4.1.2). For days to first female flower appearance, genotypes under optimum environments exhibited a wide range from 46 days in BG-58 to 82 days in BG-47 with a mean of 61.01 days, while in heat-stress conditions, plants flowered slightly earlier, ranging from 42.33 days in BG-58 to 82 days in BG-47 with a mean of 57.24 days. The genotypic variance (σ^2g) was high, 41.32 and 40.53 under optimum and heat stress, respectively, and broad-sense heritability was very high in both environments (94.63% in optimum, 96.47% in heat stress). The genetic advance as a percent mean was also higher, at 21.11 and 22.51, indicating strong genetic control of the studied genotypes (Table 4.1.5).

Node at first female flower appearance

Node number at first female flower appearance showed a wide range of variation, for optimum environments showed a range of 12 in BG-52 to 25.33 in BG-21 with a mean of 19.19 nodes, while heat stress increased the mean to 20.30 nodes with varied from 13 in BG-36 to 30.67 in BG-21, indicated female initiation positioned later in plants during heat stress. Variability components showed genotypic variance (σ^2g) was moderate, with values of 9.52 and 15.60, while phenotypic variance exhibited 10.89 and 16.73 for optimum and heat stress condition, respectively. High heritability (87.37, 93.23%) and high genetic

advance as percent mean (30.95, 38.72%) under optimum and heat stress conditions, respectively, indicated that selection for early flowering even in stresssed environments.

Days to first edible fruit harvest

Days to first edible fruit harvest observed detrimental environmental influence in heat stress conditions. For optimum conditions, first fruit harvest required 54.33 days in BG-58 to 100 days in BG-52, whereas during heat stress, harvest was earlier than optimum with ranged of 54.33 in BG-58 to 96 in BG-47 shown on Table 4.1.2. The genotypic variance was also recorded high (49.74 optimum; 50.16 heat) and high heritability (95.40 and 97.03%) in both conditions, demonstrated their strong genetic stability (Table 4.1.5).

Sultana *et al.* (2018) reported wide variation among bottle gourd genotypes for earliness traits. They reported days to first female flower opening ranging from 45.80 to 59.67 days (mean 53.27), node number for first female flower from 15.47 to 24.50 (mean 19.60), branches per plant from 18.47 to 31.70 (mean 24.09), and days to first harvest from 60.63 to 74.67 days (mean 68.39). These results supported the present findings by confirming substantial genetic variability in flowering and maturity traits of bottle gourd. Duhan *et al.* (2022) also reported greater variability among bottle gourd genotypes, with days to first female flowering ranging from 48.6 to 65.0 days, days to first fruit harvest from 57.3 to 77.0 days, primary branches per vine from 8.7 to 16.1, nodes to first female flower from 9.8 to 15.2, and fruits per vine from 4.4 to 11.1. These findings indicated substantial genetic diversity, supporting the variation observed in the present study.

Rambabu *et al.* (2017) reported high heritability for days to first male flower (95%), first female flower (94%), and first fruit harvest (94%), with moderate GA% (20.83–23.09%), indicating strong genetic control and good potential for selecting early-maturing genotypes, consistent with the present study. Harika *et al.* (2012) reported early flowering in NBBL-12 (43.83 days) with first female flower at 45.83 days and harvest at 52.83 days, while NBOH-1 and Sarika were late, with first female flower at 60.67 days, harvest at 75.00 days, and flowers on higher nodes (12.00–13.83). Male and female flowers appeared on lower nodes in Louki (5.83 and 6.83), whereas Champion flowered on higher nodes. These results were consistent with the present study, confirming wide genotypic variation in flowering and maturity traits.

Table 4.1.1: Analysis of variance (ANOVA) for yield and yield-contributing traits in optimum and heat stress conditions

Traits	Optimum Conditions			Heat stress condition		
	Replicate df=2	Genotype df=57	Error df=114	Replicate df=2	Genotype df=38	Error df=76
Days to first flower appearance	1.02	126.30 **	2.35	0.82	123.07 **	1.48
Node of 1st appearance	1.34	29.92 **	1.38	2.45	47.93 **	1.13
Days to first edible fruit harvest	1.63	151.62 **	2.4	3.13	152.00 **	1.54
Internode length (cm)	0.27	14.85 **	0.64	0.26	17.71 **	0.68
Number of Primary branches	0.63	32.87 **	0.95	2.76	22.75 **	1.03
Fruit length (cm)	0.95	260.48 **	0.57	1.54	213.00 **	0.81
Fruit diameter (cm)	0.12	19.43 **	0.19	0.28	21.91 **	0.19
Number of Fruits per plant	0.08	16.64 **	0.84	0.44	21.56 **	0.55
Fruit weight (kg)	0.03	0.29**	0.018	0.004	0.16**	0.014
Yield per plant (kg)	0.48	54.96 **	0.7	0.57	49.14 **	0.3
Total soluble solids (°Brix)	0.01	0.02**	0.020	0.02	0.01**	0.09
Dry matter (%)	0.63	1.25**	6.211	0.61	1.28**	4.91
Vitamin C (mg 100 g^{-1})	0.04	0.009**	0.006	0.02	0.03**	0.04
Yield per hectare (t ha^{-1})	1.91	219.84 **	2.81	2.29	196.57 **	1.2

Here, df= Degrees of freedom; *p≤0.05 and **p≤0.01 level of probability.

Table 4.1.2: Mean performance and DMRT test for earliness and growth traits of bottle gourd evaluated under normal and heat stress conditions

Genotype	Days to first female flower appearance		Node at first female appearance		Days to first edible fruit harvest		Internode length		Number of primary branches	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-01	51.97 u	49.22 u	16.10 r–t	17.00 l–m	62.83 x–y	60.28 o–p	15.90 e–h	15.56 f–h	13.63 r	11.72 i–m
BG-02	55.10 r–t	49.94 t–u	15.90 r–t	16.67 l–m	66.27 t–w	61.11 n–o	13.10 l–o	13.28 l–m	15.73 l–p	10.78m–n
BG-03	59.50 i–m	56.06 j–m	17.00 p–s	16.72 l–m	69.83 n–r	63.56 k–m	12.83 m–p	12.89 n–o	16.87 i–m	12.56 h–l
BG-04	59.93 h–l	0	20.93 e–i	0	71.67 m–o	0	15.57 e–i	0	15.57 l–q	0
BG-05	58.97 j–n	62.06 d–e	20.20 g–l	16.72 l–m	68.87 p–s	71.89 d–f	15.63 e–h	15.61 f–g	16.10 j–o	9.06 o–p
BG-06	55.27 q–t	54.78 l–o	17.30 o–s	18.28 k–l	65.80 u–w	67.28 h	13.27 l–o	13.89 j–k	14.57 o–q	8.72 p
BG-07	54.23 s–u	52.67 q–r	20.50 f–k	15.67m–n	65.63 u–w	61.83 m–n	15.77 e–h	14.11 i–j	14.90 n–q	10.33m–o
BG-08	64.33 f–g	59.00 g–h	17.67 n–r	22.00 d–h	76.33 g–j	70.33 f–g	8.83 r	7.00 t	14.33 p–q	12.67 h–k
BG-09	58.33 j–o	0	19.67h–m	0	71.67m–o	0	15.33 f–i	0	19.33 b–f	0
BG-10	67.33 d–e	66.33 b	22.67 b–e	22.00 d–h	80.00 c–e	76.67 b	15.33 f–i	21.00 a	20.00 a–d	22.33 a
BG-11	62.00 g–h	0	23.67 a–d	0	74.33 j–l	0	21.33 a	0	21.00 a	0
BG-12	57.33 m–r	57.33 h–j	20.67 f–j	14.67 n–o	68.33 q–t	67.00 h	13.33 l–n	14.33 h–l	17.33 h–k	13.67 g–h
BG-13	59.00 j–n	0	22.00 d–g	0	70.00 n–r	0	18.33 b–c	0	18.00 f–i	0
BG-14	80.00 a	0	15.67 s–t	0	91.67 b	0	16.33 e–f	0	11.67 s	0
BG-15	59.67h–m	0	12.33 v	0	69.33 o–s	0	13.67 k–n	0	17.67 g–j	0
BG-16	58.33 j–o	53.00 p–q	18.33 l–q	21.67 d–h	67.67 r–u	63.67 j–l	14.67 h–k	13.33 k–q	19.33 b–f	12.67 h–k
BG-17	57.00 n–r	56.00 j–m	16.00 r–t	19.67 i–k	67.67 r–u	65.33 h–k	11.00 q	15.67 e–h	19.33 b–f	15.67 d–e
BG-18	60.33 h–k	56.00 j–m	21.33 e–h	22.67 d–f	71.33m–p	67.00 h	16.67 d–e	18.00 b–c	21.00 a	18.00 b
BG-19	57.67 l–q	56.00 j–m	23.67 a–d	21.33 e–i	70.33 n–q	66.33 h–i	13.00 m–o	13.33 k–q	18.67 d–h	13.67 g–h
BG-20	67.33 d–e	0	21.00 e–i	0	78.33 e–h	0	11.67 p–q	0	7.67 t	0

Note: Means followed by the same letter(s) within a column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% probability level. Means with different letter (s) indicate significant differences ($P \leq 0.05$).

Table 4.1.2: Mean performance and DMRT test for earliness and growth traits of bottle gourd under normal and heat stress conditions (Cont'd)

Genotype	Days to first female flower appearance		Node at first female appearance		Days to first edible fruit harvest		Internode length		Number of branches	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-21	60.00 h–l	56.67 j–l	25.33 a	30.67 a	72.33 l–n	71.00 e–g	14.67 h–k	14.33 h–l	20.67 ab	17.33 b–c
BG-22	59.67 h–m	0	22.33 c–f	0	73.00 k–m	0	14.67 h–k	0	14.00 q–r	0
BG-23	59.00 j–n	0	17.33 o–s	0	73.00k–m	0	14.33 i–l	0	16.00 k–o	0
BG-24	57.33 m–r	55.67 j–n	15.67 s–t	14.00 o–p	69.33 o–s	65.67 h–j	14.33 i–l	14.00 i–o	20.67 ab	9.33 n–o
BG-25	58.00 k–p	0	15.67 s–t	0	70.00 n–r	0	9.67 r	0	14.00 q–r	0
BG-26	60.00 h–l	0	18.00m–q	0	72.00 l–n	0	14.67 h–k	0	17.33 h–k	0
BG-27	60.33 h–k	0	17.67 n–r	0	71.67m–o	0	17.67 c–d	0	18.67 d–h	0
BG-28	58.00 k–p	55.00 l–n	19.00 j–o	21.67 d–h	69.00 p–s	64.33 i–l	12.00 o–q	13.67 j–p	18.33 e–i	16.33 c–e
BG-29	71.00 b	0	22.33 c–f	0	81.00 c–d	0	14.67 h–k	0	20.33 a–c	0
BG-30	71.33 b	0	24.67 a	0	82.33 c	0	15.67 e–h	0	17.00 i–l	0
BG-31	60.67 h–j	0	19.33 i–n	0	71.33m–p	0	14.33 i–l	0	19.33 b–f	0
BG-32	62.00 g–h	58.67 g–i	24.00 a–c	21.33 e–i	72.00 l–n	69.67 g	16.33 e–f	15.00 f–j	15.33 m–q	10.67m–n
BG-33	58.33 j–o	0	16.00 r–t	0	68.33 q–t	0	17.67 c–d	0	15.00 n–r	0
BG-34	55.00 r–t	59.00 g–h	17.67 n–r	28.33 b	65.67 u–w	73.33 c–d	19.00 b	18.00 b–c	20.33 a–c	15.00 e–g
BG-35	52.00 u	51.00 s–u	18.00m–q	20.33 h–j	62.33 y	60.67 o–p	15.67 e–h	14.67 g–k	17.00 i–l	15.00 e–g
BG-36	56.00 o–s	54.00 n–p	16.67 q–s	13.00 p	64.00 w–y	66.67 h	13.33 l–n	16.00 d–g	16.00 k–o	16.33 c–e
BG-37	72.00 b	64.67 b–c	21.33 e–h	23.33 c–d	80.33 c–e	75.67 b	15.00 g–j	17.00 c–e	19.00 c–g	13.00 h–j
BG-38	62.00 g–h	64.00 c–d	22.67 b–e	22.00 d–h	68.67 q–t	71.67 d–g	15.67 e–h	15.67 e–h	19.00 c–g	14.00 f–h
BG-39	55.67 p–s	54.67m–n	19.33 i–n	20.67 g–j	65.00 v–x	63.00 l–m	14.33 i–l	12.33 p–q	16.33 j–n	15.33 e–f
BG-40	67.00 d–e	61.33 e–f	22.00 d–g	23.00 d–e	76.00 h–j	72.67 c–e	15.67 e–h	19.00 b	20.67 ab	14.00 f–h

Table 4.1.2: Mean performance and DMRT test for earliness and growth traits of bottle gourd under normal and heat stress conditions (Cont'd)

Genotype	Days to first female flower appearance		Node at first female appearnce		Days to first edible fruit harvest		Internode length		Number of primary branches	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-41	57.00 n–r	54.33m–o	20.33 g–k	19.67 i–k	67.00 s–v	57.67 q	14.67 h–k	15.33 f–i	15.33 m–q	13.00 h–j
BG-42	56.67 n–s	57.00 i–k	18.33 l–q	23.00 d–e	66.33 t–w	72.00 d–f	16.00 e–g	12.67 o–p	18.67 d–h	17.00 b–d
BG-43	65.67 e–f	61.67 e–f	17.00 p–s	19.33 j–k	77.00 f–i	74.67 b–c	15.00 g–j	15.67 e–h	13.67 r	11.00 l–m
BG-44	61.67 h–i	60.33 e–g	24.33 a–b	29.94 a–b	72.33 l–n	73.28 c–d	14.67 h–k	16.06 d–f	19.67 a–e	15.50 d–f
BG-45	60.00 h–l	55.44 j–o	14.67 t–u	21.56 e–h	70.67 m–q	66.94 h	15.00 g–j	14.56 h–l	18.33 e–i	16.50 b–e
BG-46	57.00 n–r	55.33 k–o	20.00 h–l	21.33 e–i	65.33 u–x	69.67 g	13.00 m–o	14.33 h–l	14.00 q–r	11.67 j–l
BG-47	66.67 d–f	82.00 a	19.33 i–n	25.00 c	77.33 f–i	96.00 a	14.00 j–m	10.00 s	17.33 h–k	13.33 h–i
BG-48	58.67 j–n	0	19.33 i–n	0	70.33 n–q	0	12.00 o–q	0	13.67 r	0
BG-49	72.00 b	0	23.67 a–d	0	80.67 c–e	0	14.00 j–m	0	14.33 p–q	0
BG-50	68.33 c–d	64.33 c	22.67 b–e	19.67 i–k	77.00 f–i	75.67 b	15.67 e–h	14.67 g–k	16.00 k–o	11.33 k–l
BG-51	70.33 b–c	53.67 o–p	21.00 e–i	21.00 f–j	78.67 d–g	66.00 h–i	18.00 b–c	17.33 c–d	14.00 q–r	13.67 g–h
BG-52	80.00 a	0	12.00 v	0	100.00 a	0	18.67 b–c	0	12.00 s	0
BG-53	57.00 n–r	51.33 r–t	16.67 q–s	20.33 h–j	65.67 u–w	60.67o–p	12.67 n–p	11.67 r	15.33 m–q	13.00 h–j
BG-54	58.00 k–p	55.00 l–n	13.00 u–v	16.33 m–n	68.67 q–t	65.33h–k	15.00 g–j	15.00 f–j	15.00 n–r	12.67 h–k
BG-55	64.33 f–g	60.00 f–g	21.00 e–i	22.33 d–g	75.33 i–k	67.00 h	12.67 n–p	13.00 m–r	17.33 h–k	14.00 f–h
BG-56	67.33 d–e	65.33 b–c	16.00 r–t	16.00 m–n	79.00 d–f	73.00 c–e	13.33 l–n	13.33 k–q	8.67 t	13.33 h–i
BG-57	53.00 t–u	51.00 s–u	17.33 o–s	17.00 l–m	62.00 y	59.00p–q	11.00 q	12.00 q–r	8.33 t	10.67m–n
BG-58	46.00 v	42.33 v	18.67 k–p	15.67 m–n	57.00 z	54.33 r	14.67 h–k	14.50 h–l	7.33 t	16.00 c–e
Min	46	0	12	0	54.33	0	8.83	0	7.33	0
Max	82.00	82.00	25.33	30.67	100.00	96.00	21.33	21.00	21.00	22.33
Mean	61.01	57.24	19.19	20.3	71.82	67.89	14.56	14.56	16.32	13.61
SE (±)	0.88	0.7	0.68	0.61	0.89	0.72	0.6543	0.6756	0.7978	0.8276
$CD_{0.05}$	2.48	1.98	1.9	1.73	2.5	2.02	1.2961	1.3455	1.5805	1.6482

Here, SE= Standard error, CD= Critical difference

Internode length (cm)

Internode length varied moderately, with similar means in optimum condition ranging from 8.83 to 21.33 with a mean of 14.67 cm, while for heat stress it ranged from 7 to 21, with mean 14.56 cm (Table 4.1.2). There were exhibited small genotypic (σ^2g) variance (4.73 optimum; 5.67 heat) and high heritability (88.06 and 89.24%, respectively). It was indicated that internode length genetically governed trait despite heat induced reductions in cell expansion.

Number of primary branches per plant

The number of primary branches showed pronounced environmental sensitivity. The branches per plant recorded a mean of 16.32 with ranged 7.33–21 under optimum conditions, while 13.61 with ranged 8.72–22.33 under heat stress indicating that decreased number of branches. The estimated high heritability (91.76%, 87.61%) and moderate GCV (19.98, 19.77%) indicated that branching offered scope for improvement under both environments.

Fruit length and diameter

Fruit length exhibited greater variability among the genotypes, with optimum conditions ranged from 12.89 cm in BG-05 to 48 cm in BG-48, while under heat stress conditions it varied from 11.39 cm in BG-05 to 43.05 cm in BG-28 (Table 4.1.3). The mean fruit length was 31.23 cm under optimum conditions, while during heat stress it reduced to 26.76 cm. The phenotypic variance remained very large (87.21 in optimum; 70.87 in heat), and heritability was nearly complete (99.34%, 98.86%); genetic advance as a percent mean, 61.19 and 56.17, showed that there was strong genetic control and excellent potential for selection even under stress.

Fruit diameter also followed a similar pattern, with means decreasing from 13.07 cm under optimum conditions to 11.86 cm in heat stress. The range was 7.97 in BG-06 to 20.82 cm in BG-29 for optimum condition, while for heat stress it was varied from 6.04 in BG-06 to 16.55 cm in BG-57. Extremely high heritability (97%) existed in both conditions, and genetic advance as percent mean (39.34 and 41.08%) indicated stable inheritance despite environmental influence (Table 4.1.5).

Sultana *et al.* (2018) reported wide variation in fruit traits of bottle gourd, with fruit length ranging from 14.33 to 49.25 cm (mean 30.81 cm) and fruit girth from 8.25 to 16.37 cm (mean 11.57 cm) during optimum season. These results were fully align and identical with the findings of the present study. Duhan *et al.* (2022) reported fruit length ranging from 24.2 to 36.8 cm and fruit diameter from 7.3 to 10.5 cm, which were closely aligned with the present findings. Rambabu *et al.* (2017) exhibited fruit width (96%) and fruit length (89.9%) with high heritability with very high GA% (74.79% and 74.03%), suggesting substantial genetic variation and scope for improving fruit size, which was in line with current observations.

Yield and key yield-contributing traits

The number of fruits per plant exhibited strong heat stress sensitivity of the studied genotypes (Table 4.1.3). The mean performance declined from a mean of 9.67 in optimum condition to 7.91 under heat stress. The number of fruits ranged from 5.67 in BG-15 to 18.33 in BG-43 at optimum condition and 3.67 in BG-34 to 13 in BG-43 under heat stress. The trait expressed high heritability (86.31%, 92.05%) and considerable genetic advance (45.44%, 36.77%), confirming strong additive gene action, making fruit number an effective criterion for selection under both environments.

Fruit weight recorded a reduction under heat stress in a mean of 1.52 kg, ranged from 1.03 in BG-06 to 2.62 in BG-48, compared to the optimum of a mean of 1.92 kg and a range of 1.23 in BG-06 to 1.94 in BG-45. The genotypic variance was negligible in both environments, heritability remained extremely high (>97%) at 98.08 and 97.29%, and genetic advance over mean reached higher (32.75%, 51.31%) under optimum and heat stress, indicating very strong response to selection.

Yield per plant was substantially affected by the high temperature in the studied bottle gourd genotypes. The yield under optimum conditions ranged from 10.56 with BG-06 to 26.98 in BG-48, while during heat stress conditions it varied from 5.65 in BG-34 to 20.36 in BG-02. The decreasing trend decreases a mean of performance from 18.45 kg under the optimum conditions to 12.58 kg under heat stress. Despite environmental influence, both GCV (32.05, 23.05) and PCV (32.34, 23.50) remained high (23–32%), and heritability exceeded 96%, confirming that genotypic differences strongly determine yield potential even during heat stresss condition.

Table 4.1.3: Mean performance and DMRT test for fruit and yield components of bottle gourd under optimum and heat stress

Genotypes	Fruit length (cm)		Fruit Diameter (cm)		Number of fruits per plant		Fruit weight (kg)		Yield per plant (kg)	
	Fruit length	Fruit length	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-01	32.99 l–n	30.49 ij	10.88 r–w	10.19 m–o	11.97 c–e	9.61 d–f	1.93 o–r	1.59 k–m	22.97 e-g	16.83 d
BG-02	35.17 k	32.63 e-g	11.60 n–q	10.62 k–n	12.10 c–e	10.78 cd	2.16 h–i	1.86 b	25.62 a–c	20.36 a
BG-03	31.85 n–o	28.68 kl	11.62 n–q	10.24 l–o	12.57 c	6.33 kl	1.73 u–w	1.18 t–u	21.16 i–k	11.79h-i
BG-04	45.22 b	0	11.58 n–r	0	11.87 c–e	0	1.94 o–q	0	22.78 f–g	0
BG-05	12.89 b	11.39 v	16.49 d–e	15.22 b–d	8.10 l–p	6.00 lm	1.73 u–w	1.40 q–r	18.33 p–s	13.78 g
BG-06	32.57 m–n	36.28 c	7.97 y	6.04 u	8.57 j–n	7.39 jk	1.23 b	1.03 w	10.56 f	5.68 p
BG-07	31.81 n–o	27.63 l-n	11.43 o–r	10.46 k–o	9.93 g–j	8.89 e–h	1.92 q–r	1.48 o–p	18.94 o–r	13.76 g
BG-08	30.18 p–q	28.45 k-m	13.63 h–i	11.70 i	9.33 h–l	8.67 f–i	1.76 u–v	1.59 k–n	15.76 v–x	10.53 j–l
BG-09	30.27 p	0	11.53 o–r	0	8.33 k–o	0	1.78 t–u	0	13.75 z–b	0
BG-10	21.53 w–x	19.75 p-r	15.93 e–f	14.35 f–g	6.00 r–s	5.33 l–o	2.16 h–i	1.77 d–e	13.27 a–c	9.69 l-m
BG-11	25.03 s–t	0	15.00 g	0	6.00 r–s	0	2.00 l–p	0	11.85 d–f	0
BG-12	38.38 f–g	33.28 d-f	13.07 i–k	10.97 j–k	6.33 q–s	4.33 o–q	2.33 c–d	1.71 f–h	14.20 y–a	8.44 n
BG-13	38.60 f–g	0	11.70 n–q	0	10.33 f–i	0	2.34 c–d	0	25.37 b–d	0
BG-14	38.69 f–g	0	11.68 n–q	0	6.33 q–s	0	2.20 f–h	0	14.40 y–a	0
BG-15	30.92 o–p	0	13.93 h	0	5.67 s	0	2.24 e–f	0	13.62 z–c	0
BG-16	32.72 l–n	29.67 jk	11.47 o–r	10.27 k–o	8.67 j–n	8.33 g–j	2.17 g–i	1.63 i–l	20.61 j–l	14.13f–g
BG-17	29.00 q–r	27.80 l-n	11.62 n–q	10.38 k–o	10.67 e–h	8.33 g–j	1.64 x–y	1.21 t–u	17.78 q–s	12.33 h
BG-18	43.47 c–d	37.33 bc	10.22 w–x	8.63 r	9.67 g–k	9.46 e–g	1.57 y	1.35 r–s	13.95 y-a	12.53 h
BG-19	24.20 s–u	30.80 h-j	11.37 p–s	6.78 t	7.33 n–r	4.67 n–q	1.69 v–x	1.43 p–q	12.75 b–e	6.16 p
BG-20	23.35 u–v	0	16.43 e	0	9.00 i–m	0	1.39 z–a	0	11.68 e–g	0

Note: Means followed by the same letter(s) within a column are not significantly different at the 5% probability level according to Duncan's Multiple Range Test (DMRT). Means with different letter(s) indicate significant differences ($P \leq 0.05$).

Table 4.1.3: Mean performance and DMRT test for fruit and yield components of bottle gourd under optimum and heat stress (Cont'd)

Genotypes	Fruit length (cm)		Fruit Diameter (cm)		Number of fruits per plant		Fruit weight (kg)		Yield per plant (kg)	
	Fruit length	Fruit length	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-21	41.28 e	36.00 c	12.02 m–p	10.83 k–m	8.67 j–n	7.67 ij	2.21 f–h	1.85 b–c	19.63 l–p	14.27f-g
BG-22	44.32 b–d	0	10.90 r–w	0	9.67 g–k	0	1.88 q–s	0	17.66 q–s	0
BG-23	43.38 c–d	0	9.88 x	0	7.00 o–r	0	2.02 k–m	0	13.62 z–c	0
BG-24	28.85 r	32.07 f-h	12.12 l–o	9.70 p–q	11.00 d–g	5.33 l–o	2.29 d–e	1.59 k–m	25.45 b–c	8.42 n
BG-25	36.80 h–i	0	10.48 u–x	0	7.67 m–q	0	1.46 z	0	12.34 c–e	0
BG-26	38.97 f	0	11.18 q–u	0	10.00 g–j	0	2.52 b	0	24.06 d–f	0
BG-27	38.37 f–g	0	11.40 p–r	0	7.33 n–r	0	2.09 j–k	0	14.81 x–z	0
BG-28	38.38 f–g	43.05 a	11.13 q–v	9.20 q–r	9.33 h–l	8.67 f–i	2.18 f–h	1.94 a	19.44 m–p	16.49 d
BG-29	20.40 x–y	0	20.82 a	0	9.33 h–l	0	2.23 e–g	0	19.10 n–q	0
BG-30	35.42 j–k	35.42 jk	11.95 m–p	0	8.33 k–o	0	2.22 e–h	0	19.04 n–q	0
BG-31	25.17 s	25.17 s	15.23 f–g	0	8.00 l–p	0	2.04 j–m	0	17.59 r–t	0
BG-32	45.45 b	38.38 b	12.12 l–o	10.15 m–o	7.33 n–r	4.00 pq	2.05 j–m	1.59 k–m	14.93 w–z	7.13 o
BG-33	23.73 u–v	0	13.17 i–k	0	10.00 g–j	0	1.43 z	0	11.77 e–f	0
BG-34	43.27 d	38.15 b	10.47 v–x	7.53 s	6.67 p–r	3.67 q	1.99 m–p	1.41 q–r	13.19 a–d	5.65 p
BG-35	23.83 t–u	24.13 o	13.32 h–j	12.55 h	11.67 c–f	11.03 cd	1.36 a	1.22 t–u	16.23 u–w	14.54e–g
BG-36	32.87 l–n	24.30 o	12.75 j–l	12.45 h	10.00 g–j	9.28 e–h	1.94 n–q	1.72 e–g	20.33 j–n	16.57 d
BG-37	23.65 u–v	20.00 p-r	16.43 e	15.17 b–e	11.67 c–f	9.67 d–f	1.83 s–t	1.65 h–k	22.59 g–h	16.87 d
BG-38	44.53 b–c	36.98 bc	10.65 t–w	9.85 o–q	11.00 d–g	6.33 kl	2.06 j–l	1.73 d–f	22.11 g–i	10.23j–l
BG-39	29.02 q–r	27.13 mn	12.58 k–m	12.23 i	11.67 c–f	10.00 de	1.84 s–t	1.79 c–d	19.68 l–p	17.37 d
BG-40	15.90 a	14.62 t	17.87 b–c	15.63 b–c	10.33 f–i	6.33 kl	2.10 i–j	1.37 r–s	20.73 j–m	9.57 m

Table 4.1.3: Mean performance and DMRT test for fruit and yield components of bottle gourd under optimum and heat stress (Cont'd)

Genotype	Fruit length (cm)		Fruit diameter (cm)		Number of fruits/plant		Fruit weight (kg)		Yield per plant (kg)	
	Fruit length	Fruit length	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-41	16.22 a	14.33 t	14.97 g	13.07 h	9.33 h–l	5.00 m–p	2.01 l–n	1.53 n–o	18.36 p–s	7.25 o
BG-42	15.10 a	13.75 tu	16.30 e	15.67 b–c	9.33 h–l	8.33 g–j	1.71 u–x	1.60 j–m	15.25 v–x	14.42e-g
BG-43	22.60 v–w	18.67 r	12.48 k–m	10.92 j–l	18.33 a	13.00 a	1.42 z–a	1.21 t–u	25.92 a–b	19.36 b
BG-44	33.33 l–m	31.36 g-i	11.32 p–s–t	10.10 n–p	8.33 k–o	4.33 o–q	2.18 f–h	1.55 m–n	21.31 h–j	11.08 i–j
BG-45	29.70 p–r	26.53 n	14.90 g	13.90 g	11.00 d–g	9.17 e–h	2.00 l–o	1.96 a	20.94 i–l	18.36 c
BG-46	20.60 x	18.95 qr	15.83 e–f	14.47 e–g	7.67 m–q	5.67 l–n	1.87 r–s	1.62 i–l	14.20 y–a	10.10k-m
BG-47	36.50 i–j	32.67 e-g	12.27 l–n	10.47 k–o	11.00 d–g	6.33 kl	1.67 w–x	1.16 u–v	19.91 k-o	10.44j-m
BG-48	48.00 a	0	11.53 o–r	0	10.33 f–i	0	2.62 a	0	26.98 a	0
BG-49	44.75 b	0	11.12 q–v	0	9.00 i–m	0	2.20 f–h	0	20.49 j–m	0
BG-50	37.50 g–i	23.67 o	11.68 n–q	9.88 o–q	9.33 h–l	4.67 n–q	1.84 s–t	1.32 n–q	20.07 j-n	6.16 p
BG-51	37.85 f–h	34.53 d	13.05 i–k	11.57 i–j	9.67 g–k	5.33 l–o	2.37 c	1.57 l–n	22.76 f–g	10.85j–k
BG-52	37.83 f–h	0	10.67 s–w	0	8.33 k–o	0	2.02 k–m	0	17.60 r–t	0
BG-53	33.80 l	34.00 de	11.77 n–q	11.68 i	13.00 c	11.67 bc	1.41 z–a	1.33 s	18.46 p–s	15.17 e
BG-54	13.13 b	12.70 uv	15.70 f–g	15.23 b–d	15.00 b	11.67 bc	1.43 z–a	1.24 t	21.18 i–k	14.88 e–f
BG-55	18.12 z	17.00 s	17.19 c–d	15.87 a–b	9.67 g–k	8.33 g–j	1.67 w–x	1.48 o–p	16.38 t–v	13.88 g
BG-56	19.33 y–z	15.12 t	18.35 b	14.77 d–f	9.00 i–m	8.00 h–j	1.93 p–r	1.68 f–i	17.56 s–u	14.00f–g
BG-57	22.53 v–w	21.18 p	17.18 c–d	16.55 a	12.33 c–d	10.98 cd	1.83 s–t	1.66 g–j	24.31 c–e	19.40 b
BG-58	22.00 w	20.17 pq	16.48 d–e	15.12 c–e	14.67 b	12.67 ab	1.65 x	1.12 v	24.71 b–d	12.23 h
Min	12.89	0.00	7.97	0.00	5.67	0.00	1.23	0.00	10.56	0.00
Max	48.00	43.05	20.82	16.55	18.33	13.00	2.62	1.96	26.98	20.36
Mean	31.23	19.04	13.07	7.97	9.67	5.32	1.92	1.02	18.45	12.58
SE (±)	1.22	1.86	0.33	0.79	0.31	0.56	0.04	0.10	0.48	0.32
CD 0.05	1.22	1.46	0.70	0.70	1.48	1.21	0.07	0.06	1.36	0.89

Several researchers also demonstrated similar findings for yield contributing traits. Sultana *et al.* (2018) reported that number of fruits per plant ranged from 3.40 to 8.13 (mean 5.13), fruit weight from 1.26 to 1.92 kg (mean 1.61 kg), and yield from 17.47 to 39.76 t/ha (mean 27.43 t/ha). These values were closely matched with the trends observed in the present study, indicating similar yield potential and variability. Duhan *et al.* (2022) observed average fruit weight ranged from 530 to 1100 g and fruit yield from 172.5 to 358.5 q/ha, which were in contrast with the findings of the present study. Harika *et al.* (2012) reported wide variation in yield traits. Gaja produced the highest fruits per vine (14.50) and yield (15.81 kg/vine; 41.68 t/ha), while INDAM-320 had heaviest fruits (1443.09 g) and Champion lowest yield (2.27 kg/vine; 10.29 t/ha; 698.90 g). These results were aligned with the findings of the present study.

Quality parameters

Quality traits showed relatively stable performance over the environments, as shown in Table 4.1.4. Total soluble solids (TSS) increased slightly under heat stress (mean 2.7 vs. 2.68). TSS ranged from 1.8 in BG-54 to 4.5 in BG-42, while for heat stress it varied from 1.77 to 4.27. The genotypic, phenotypic, and environmental variance increased under heat, resulting in lower heritability (74.91%) compared to optimum (92.14%). Genetic advance over mean was higher in optimum than heat stress conditions.

Dry matter content remained similar across environments, it ranged from 3.7 in BG-53 to 7.2 in BG-51 with mean 4.95 mg/100 g during optimum condition, while it varied from 3.56 in BG-45 to 6.33 in BG-51 with mean 4.69 mg/100 g during heat stress. There weas extremely high heritability (>93.66%, 99.05%), reflecting its robustness and heritability to heat. Ascorbic acid content increased slightly with heat (7.25 vs. 7.09 mg/100 g), it varied from 5.08 in BG-10 to 9.47 in BG-26 during optimum conditions, while during heat environments it ranged from 4.97 with BG-57 to 9.27 in BG-07. The high heritability (98.67, 97.27%) and high genetic advance over mean (34.86, 33.16) indicated strong genetic control and potential for improving nutritional quality under both conditions. Rambabu *et al.* (2017) showed TSS (86%), total sugar (94%), and ascorbic acid (98%) exhibited high heritability with moderate GA% (25–28%), confirming strong genetic control and potential for improving fruit quality traits, which was consistent with current results.

Table 4.1.4: Quality traits performance under optimum and heat stress conditions in bottle gourd

Genotypes	Total soluble solids (TSS)		Dry matter content (mg/100g)		Ascorbic acid (mg 100 g^{-1})	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-01	3.03 f-h	2.93 ef	4.83 jk	4.78 jk	8.32 de	8.21 cd
BG-02	3.20 e-g	3.07 de	4.50 jk	4.22 kl	7.35 de	7.06 de
BG-03	2.20 ij	2.23 h-j	4.35 kl	4.28 kl	8.39 de	8.45 cd
BG-04	3.43 a-c	0	6.00 ef	0	5.60 fg	0
BG-05	2.27 h-j	2.23 h-j	4.55 jk	4.67 ij	8.36 de	8.50 cd
BG-06	2.65 g-i	2.57 g-i	4.75 jk	4.63 ij	8.05 de	8.10 cd
BG-07	2.20 ij	2.37 h-j	3.82 m	3.79 m	9.14 ab	9.27 a
BG-08	2.50 g-i	2.53 g-i	5.70 de	5.67 de	5.58 fg	5.73 fg
BG-09	2.20 ij	0	4.80 kl	0	8.11 de	0
BG-10	2.40 h-j	2.40 h-j	4.33 kl	4.50 jk	5.08 i	5.23 hi
BG-11	2.40 h-j	0	4.37 kl	0	6.06 fg	0
BG-12	2.57 g-i	2.70 f-h	4.67 ij	4.67 ij	7.94 cd	7.90 de
BG-13	2.07 jk	0	5.34 fg	0	8.02 cd	0
BG-14	3.23 c-e	0	3.57 m	0	6.81 ef	0
BG-15	1.87 k	0	5.10 fg	0	6.03 gh	0
BG-16	3.13 d-f	3.00 de	3.80 lm	3.67 lm	8.17 bc	8.17 cd
BG-17	1.92 k	1.97 jk	5.17 fg	5.00 gh	5.94 gh	5.92 gh
BG-18	2.73 f-h	2.60 g-i	5.07 ef	5.03 gh	8.11 cd	7.80 de
BG-19	2.83 f-h	3.00 de	5.87 cd	5.63 de	7.89 cd	7.33 de
BG-20	2.03 jk	0	5.07 fg	0	5.77 gh	0
BG-21	2.97 d-f	2.97 de	4.00 lm	3.63 lm	8.46 bc	8.40 bc
BG-22	2.50 g-i	0	4.53 ij	0	8.20 de	0
BG-23	2.63 g-i	0	4.30 jk	0	8.24 de	0
BG-24	2.60 g-i	2.63 g-i	4.27 jk	4.00 lm	8.41 bc	8.40 bc
BG-25	2.60 g-i	0	4.10 kl	0	5.98 gh	0
BG-26	3.07 d-f	0	4.93 hi	0	9.97 a	0
BG-27	2.37 h-j	0	4.40 jk	0	8.28 bc	0
BG-28	2.60 g-i	2.57 g-i	4.37 jk	5.36 ef	8.11 cd	8.30 bc
BG-29	2.43 h-j	0	4.83 hi	0	5.99 gh	0
BG-30	3.60 ab	0	5.83 cd	0	6.33 fg	0

Table 4.1.4: Quality traits performance under optimum and heat stress conditions in bottle gourd (Cont'd)

Genotypes	Total soluble solids (TSS)		Dry matter content (mg/100g)		Ascorbic acid (mg 100 g^{-1})	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
BG-31	3.00 d-f	0	5.03 gh	0	8.02 cd	0
BG-32	2.83 f-h	2.87 ef	4.60 ij	4.73 ij	5.45 hi	5.47 hi
BG-33	2.57 g-i	0	4.43 jk	0	8.41 bc	0
BG-34	2.57 g-i	2.43 h-j	4.60 jk	4.33 kl	8.14 cd	8.17 cd
BG-35	2.60 g-i	2.73 f-h	4.63 jk	4.60 ij	8.07 cd	8.23 cd
BG-36	2.60 g-i	2.57 g-i	4.83 hi	4.47 jk	5.94 gh	6.10 fg
BG-37	2.60 g-i	2.67 f-h	4.73 hi	4.53 jk	5.48 hi	5.50 hi
BG-38	2.77 f-h	2.83 ef	4.97 gh	5.03 gh	7.20 de	7.33 de
BG-39	1.97 jk	2.20 ij	4.33 kl	4.17 kl	5.86 gh	5.97 gh
BG-40	2.40 h-j	2.57 g-i	4.73 jk	4.67 ij	7.07 ef	7.20 de
BG-41	2.67 g-i	2.50 g-i	4.62 jk	4.47 jk	8.15 bc	7.97 cd
BG-42	4.50 a	4.27 a	4.33 kl	4.17 kl	9.26 ab	9.17 ab
BG-43	2.73 f-h	2.70 f-h	4.83 hi	3.90 lm	7.59 de	6.07 fg
BG-44	2.53 g-i	2.50 g-i	4.93 jk	4.60 ij	6.68 ef	6.50 fg
BG-45	3.23 c-e	2.67 f-h	5.47 ef	3.56 m	6.16 fg	5.77 hi
BG-46	2.50 g-i	2.37 h-j	6.20 bc	5.77 cd	6.68 ef	6.30 fg
BG-47	2.80 f-h	2.67 f-h	4.67 jk	4.70 ij	6.81 ef	6.73 ef
BG-48	2.70 f-h	0	4.57 jk	0	6.72 ef	0
BG-49	2.10 jk	0	4.00 kl	0	5.77 gh	0
BG-50	2.70 f-h	2.50 g-i	6.63 ab	5.53 ef	5.28 i	5.77 hi
BG-51	2.07 jk	2.00 jk	7.20 a	6.33 a	6.68 ef	6.17 fg
BG-52	1.90 k	0	4.97 gh	0	7.81 cd	0
BG-53	3.10 d-f	3.03 de	3.70 lm	3.66 lm	9.46 ab	9.23 ab
BG-54	1.80 k	1.77 k	6.33 bc	4.80 ij	6.20 fg	5.93 gh
BG-55	3.93 ab	3.67 b	4.00 kl	3.93 lm	9.03 ab	8.87 bc
BG-56	2.33 h-j	2.27 ij	4.53 jk	4.17 kl	5.94 gh	5.90 gh
BG-57	2.90 e-g	2.70 f-h	4.43 jk	4.27 kl	5.21 i	4.97 i
BG-58	3.50 ab	3.37 c	6.12 bc	5.50 ef	6.55 ef	6.13 fg
Minimum	1.8	0.00	3.7	0.00	5.08	0.00
Maximum	4.5	4.27	7.2	6.33	9.47	9.7
Mean	2.7	2.68	4.95	4.69	7.25	7.09
SE (±)	0.12	0.11	0.05	0.06	0.04	0.07
CD (5%)	0.34	0.33	0.15	0.18	0.12	0.21

Table 4.1.5: Estimates of genetic variability parameters for various quantitative and qualitative traits in bottle gourd under optimum and heat stress conditions

Components	Days to first female flower appearance		Node of first female appearance		Days to first edible fruit harvest		Internode length		Number of primary branches		Fruit length (cm)	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
Genotypic variance (σ^2g)	41.32	40.53	9.52	15.6	49.74	50.16	4.73	5.67	10.64	7.24	86.64	70.06
Environment variance (σ^2e)	2.35	1.48	1.38	1.13	2.4	1.54	0.64	0.68	0.95	1.03	0.57	0.81
Phenotypic variance (σ^2p)	43.66	42.01	10.89	16.73	52.14	51.69	5.38	6.36	11.59	8.27	87.21	70.87
GCV (%)	10.54	11.12	16.08	19.46	9.82	10.83	14.83	11.59	19.98	19.77	29.8	31.35
PCV (%)	10.83	11.33	17.2	20.15	10.05	10.97	15.8	13.83	20.86	20.66	29.9	31.65
Broad sense heritability h^2 (%)	94.63	96.47	87.37	93.23	95.4	97.03	88.06	89.24	91.76	87.61	99.34	98.86
Genetic Advance (GA)	12.88	12.88	5.94	7.86	14.19	12.77	4.21	2.03	6.44	3.02	19.11	15.03
Genetic Advance as % of mean	21.11	22.51	30.95	38.72	19.76	18.81	28.67	13.97	39.43	22.2	61.19	56.17

Table 4.1.5: Estimates of genetic variability parameters for various quantitative and qualitative traits in bottle gourd under optimum and heat stress conditions (Cont'd)

Components	Fruit diameter (cm)		Number of fruits per plant		Fruit weight (kg)		Yield per plant (kg)		Total soluble solids (°Brix)		Dry matter (mg/100 g)		Ascorbic acid (mg/100 g)	
	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress	Optimum	Heat stress
Genotypic variance (σ^2g)	6.41	7.24	5.27	6.34	0.1	0.05	18.09	16.28	0.15	0.18	0.45	0.9	1.45	1.52
Environment variance (σ^2e)	0.19	0.19	0.84	0.55	0	0.01	0.7	0.3	0.01	0.06	0.04	0.01	0.03	0.04
Phenotypic variance (σ^2p)	6.6	7.43	6.1	6.89	0.1	0.06	18.79	16.58	0.16	0.24	0.49	0.91	1.48	1.56
GCV (%)	19.38	22.7	23.74	25.18	16.06	14.97	23.05	32.05	15.27	15.36	13.79	19.16	17.12	16.32
PCV (%)	19.66	22.87	25.55	26.12	16.21	15.15	23.5	32.34	15.91	17.87	14.33	19.25	17.33	16.55
Broad sense heritability h^2b	97.15	97.48	86.31	92.05	98.08	97.29	96.26	98.2	92.14	74.91	93.66	99.05	98.67	97.27
Genetic Advance (GA)	5.14	4.87	4.39	2.91	0.63	0.78	8.59	8.46	0.77	0.75	1.33	1.94	2.45	2.5
Genetic Advance as % of mean	39.34	41.08	45.44	36.77	32.75	51.31	46.59	67.17	30.19	27.2	27.35	39.27	34.86	33.16

4.1.3 Correlation Among Yield and Its Components Under Optimum Conditions

Correlation coefficient analysis provides information on the degree and direction of association among characters, which helps identify traits contributing directly or indirectly to yield. Correlation analysis measures and indicates the mutual relationship among various plant characters and determines the component characters on which selection can be based for genetic improvement of yield. In the present study, both genotypic and phenotypic correlation coefficients were estimated among eight quantitative characters of bottle gourd (Table 4.1.6).

Most of the values of the genotypic correlation coefficient were higher than those of the corresponding phenotypic correlations in most of the character combinations under study, which indicated that there was a genetic cause for these associations, and these observations also indicated that in the majority of the cases, the environment had not appreciably influenced the expressions of character associations. Higher genotypic correlation coefficients than their phenotypic correlation coefficients between various pairs of characters have also been observed and reported in bottle gourd by Islam *et al.* (2009), Varalakshmi *et al.* (2018), and Abhishek *et al.* (2020).

The correlation between days to first female flower appearance and days to first edible fruit harvest was highly significant and positive at both genotypic and phenotypic levels (r = 0.973 and 0.951). The association of days to first female flower appearance with node number of first female flower was positive but lower (r = 0.169 and 0.158), indicating that the early appearance of the first female flower was accompanied by its appearance on a lower node. The correlation of days to first female flower appearance with number of fruits per plant was significantly negative at both genotypic and phenotypic levels (r = -0.247 and -0.226), indicated that genotypes flowering earlier tend to bear a greater number of fruits per plant. Days to first female flower appearance also showed a significant positive correlation with fruit weight (0.243 and 0.243), revealing that late-flowering genotypes tend to produce heavier fruits, although the net effect on yield per plant was slightly negative (-0.069 and -0.063). Rathore *et al.* (2025) and Bashir *et al.* (2024) reported the similar results for days to first female flower appearance.

Table 4.1.6: Genotypic and phenotypic correlation coefficients among eight characters of bottle gourd under optimum conditions

Traits		Days to first female appearance	Node at first female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Fruit weight (kg)	Yield per Plant (kg)
Days to first female appearance	G	1	0.169*	0.973**	0.095	0.136	-0.247**	0.243**	-0.069
	P		0.158*	0.951**	0.095	0.129	-0.226**	0.243**	-0.063
Node number 1st female flower appearance	G		1	0.096	0.144	0.076	-0.252**	0.243**	-0.019
	P			0.093	0.131	0.067	-0.226**	0.225**	-0.022
Days to first edible fruit harvest	G			1	0.13	0.06	-0.285**	0.238**	-0.115
	P				0.129	0.055	-0.253**	0.237**	-0.107
Fruit length (cm)	G				1	-0.777**	-0.208**	0.403**	0.09
	P					-0.76**	-0.192*	0.399**	0.089
Fruit diameter (cm)	G					1	0.084	-0.042	0.032
	P						0.07	-0.04	0.034
Number of fruits per plant	G						1	-0.373**	0.696**
	P							-0.351**	0.662**
Fruit weight (kg)	G							1	0.368**
	P								0.358**

Here, G =Genotypic correlation, P = Phenotypic correlation, and *P<0.05, **P<0.01, respectively.

Similarly, the node number of the first female appearance exhibited significant negative correlations with the number of fruits per plant (-0.252 and -0.226), indicated lower-node flowering bears more fruits. This trait possessed a positive and significant correlation with fruit weight (0.243 and 0.225), showing that delayed flowering or higher node bearing may be compensated by heavier fruits. The trait was also negatively correlated with yield per plant.

Fruit length had a strong positive correlation recorded with fruit weight at both genotypic and phenotypic levels (0.403 and 0.399), indicating that longer fruits were generally heavier. However, fruit length was negatively correlated with fruit diameter (-0.777 and -0.760), revealing an inverse relationship between the length and diameter of fruits. Fruit length also showed a significant negative association with the number of fruits per plant (-0.208 and -0.192), suggesting that plants producing more fruits per plant tend to had shorter fruits. Fruit length showed a weak positive association with yield per plant (0.090 and 0.089) under optimum and heat-stress conditions, respectively, but was negatively correlated with fruit diameter (–0.482 and –0.483). Similar relationships among fruit length, fruit girth, and other yield-related traits have also been reported by Thakur *et al.* (2017) and Singh *et al.* (2022). The fruit diameter was positively but non-significantly correlated with the number of fruits per plant (0.084 and 0.07) and yield per plant (0.032 and 0.034) while having a non-significantly negative association with fruit weight (-0.042 and 0.04).

For the number of fruits per plant, highly significant positive correlations with yield per plant (0.696 and 0.662) were recorded. This result emphasized that the number of fruits per plant was the most important yield-determining component under optimum growing conditions. It had positively correlated with fruit diameter and negatively associated with fruit weight. Varalakshmi *et al.* (2018) also reported similar and significant positive correlation numbers of fruits (rg = 0.881, rp= 0.772) with yield per plant, and Thakur *et al.* (2017) observed similar findings on fruit numbers (0.956 and 0.760) with yield per plant.

Furthermore, fruit weight also had a highly significant positive correlation with yield per plant (0.368 and 0.358), confirming its direct and additive contribution to total yield. It had a positive correlation with fruit length (0.403, 0.399), negative association with the number of fruits per plant (-0.373, -0.351). Similar findings of negative associations of

fruit number (rg = -0.102) and negative association were observed by Sultana *et al.* (2018).

The correlation coefficient for yield per plant showed positive and significant associations with fruit length (rg = 0.090; rp = 0.089), fruit diameter (rg = 0.032; rp = 0.034), number of fruits per plant (rg = 0.696; rp = 0.662), and fruit weight (rg = 0.368; rp = 0.358), indicating that increases in fruit size, fruit number, and fruit weight were directly associated with higher yield. In contrast, yield per plant exhibited negative correlations with days to first female flower appearance (rg = -0.069; rp = -0.063), node number of first female flower appearance (rg = -0.019; rp = -0.022), and days to first edible fruit harvest (rg= -0.115; rp = -0.107), suggesting that earlier flowering and earlier fruit maturity contribute favorably to yield enhancement in bottle gourd. Similar findings of correlation for yield with different trait associations were reported by Husna *et al.* (2011), Deepthi *et al.* (2016), Thakur *et al.* (2017), Sultana *et al.* (2018), Abhishek *et al.* (2020), Singh *et al.* (2022), Bashir *et al.* (2024), and Rathore *et al.* (2025).

Previous studies strongly supported the present findings that fruit yield was primarily governed by fruit weight, number of fruits per plant, and earliness-related traits. Bashir *et al.* (2024) reported very strong positive correlations of yield with fruit yield per plant (rp = 0.99, rg = 0.98), fruit weight (rp = 0.821, rg = 0.817), number of fruits per plant (rp = 0.376, rg = 0.388), and fruit diameter (rp = 0.299, rg = 0.328), while delayed flowering and harvesting showed negative effects on yield, in agreement with the present study. Similarly, Singh *et al.* (2022) observed significant positive associations of yield with number of fruits per plant (rp = 0.810, rg = 0.785) and fruit size traits and significant negative correlations with days to flowering and first harvest, indicated the advantage of early flowering for higher productivity. Supporting these results, Kumari *et al.* (2021) reported positive correlations of yield with average fruit weight (rp = 0.775), fruit girth (rp = 0.711), and fruit length (rp = 0.699), while Mahapatra *et al.* (2019) identified fruit weight (r = 0.720), number of fruits per plant (r = 0.661), and fruit diameter (r = 0.319) as major yield-contributing traits, with delayed female flowering and harvesting reducing the yield. The consistently higher magnitude of genotypic than phenotypic correlations across studies confirms that these yield associations were largely under genetic control, thereby supporting the findings of the present investigation.

4.1.4 Path Analysis for Yield Per Plant Under Optimum Sowing Conditions

Path coefficient analysis was carried out at both genotypic and phenotypic levels to determine the direct and indirect contributions of different yield components towards yield per plant in bottle gourd. The results revealed that most of the traits were interrelated, and the direction as well as magnitude of their effects varied across the traits (Tables 4.1.7 and 4.1.8, 4.1.9). The residual effects were 0.0527 and 0.0622 at genotypic and phenotypic levels, respectively, indicating that the selected traits together explained about 94–95% of the variation in yield per plant. The highest direct and indirect effects with yield per plants for genotypic and phenotypic level are depicted in Figure 4.1.1 and Figure 4.1.2.

Days to first female appearance showed a small positive direct effect on yield at both genotypic (0.14) and phenotypic (0.132) levels. This trait had negative indirect effects through days to first edible fruit harvest, number of fruits per plant, and fruit diameter, which reduced its overall association with yield (r = -0.069 genotypic; -0.063 phenotypic). This means that although plants taking slightly more days to flower may produce heavier fruits, early flowering ultimately favors higher yield by increasing the number of fruits per plant. Therefore, selection for earlier female flower appearance would contribute positively to yield improvement. Sree *et al.* (2019) showed that days to 1st female flower appearance (0.030) exhibited a positive direct effect on fruit yield and a high positive indirect effect via node number at which 1st female flower appearance (1.248), internode length (0.064), and the number of primary branches per vine (0.025). A similar positive direct effect was also reported by Muralidharan *et al.* (2017) for days to first female flower appearance.

The node number of the first female flower showed lower positive direct effect on yield (genotypic 0.055; phenotypic 0.057). This trait exhibited a negative indirect influence via the number of fruits per plant (-0.245 and -0.206, respectively). The total correlation with yield was small and negative (-0.019 and -0.022). This indicated that genotypes that bear the first female flower on lower nodes tend to produce more fruits and higher yields. Hence, lower node flowering should be preferred for selection towards earliness and yield. Similarly, a positive direct effect on fruit yield was reported by Kalpana *et al.* (2019). Sree *et al.* (2019) reported node number at first female flower appearance showed positive direct effect (0.382) on fruit yield and showed a positive indirect effect via number of fruits per vine (0.386), internodal length (0.152), and average fruit weight (0.273).

Days to first edible fruit harvest had a negative direct effect on yield (genotypic -0.139; phenotypic -0.122). It had also possessed negative indirect contributions through the number of fruits per plant (-0.277 and -0.231, respectively) and low negative indirect effect via fruit length and diameter. Its total association with yield was negative (-0.115 and -0.107), indicated that early maturity was advantageous for higher yield. Thakur *et al.* (2017) also possessed a genotypic positive direct effect (0.206) and negative direct effects on yield per plant (-0.189), which were fully aligned with the present investigation.

Fruit length exhibited a negative direct effect on yield (genotypic -0.096; phenotypic -0.087). This trait showed a positive indirect effect through fruit weight (0.303 genotypic; 0.281 phenotypic) but exhibited negative indirect effects through the number of fruits per plant (genotypic -0.203; phenotypic -0.175). This suggested that longer fruits tend to had higher weight, which compensated for their negative direct effect on yield. Therefore, moderate fruit length coupled with higher fruit weight will be beneficial for yield improvement. Sree *et al.* (2019) reported fruit length showed negative direct effect on the fruit yield (-1.023) and positive indirect effect on fruit girth, which support the findings of the present study. While in contrast, Varalaskshmi *et al.* (2018) reported positive direct effects (0.339) and exhibited negative fruit girth (-0.272) and fruit number (-0.126) at the genotypic level.

Fruit diameter had a small negative direct effect on yield (genotypic -0.108; phenotypic -0.102). The traits possessed positive indirect effects via fruit length and number of fruits per plant. Its total correlation with yield was weak and non-significant (0.032 genotypic; 0.034 phenotypic). This indicated that changes in fruit diameter did not greatly influence yield directly.

Number of fruits per plant exhibited the highest positive direct effect on yield at both genotypic (0.974) and phenotypic (0.912) levels. It also demonstrated a strong positive correlation with yield (genotypic $r = 0.696$; phenotypic $r = 0.662$), indicating that it is the most important yield component trait. This clearly indicated that increasing the number of fruits per plant was the most effective way to improve yield in bottle gourd under optimum conditions.

Table 4.1.7: Genotypic path analysis showing direct and indirect effects of traits on yield per plant in bottle gourd in optimum season

Traits	Days to first female appearance	Node number 1st female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Fruit weight (kg)	Yield per Plant (kg)
Days to first female appearance	**0.14**	0.009	-0.136	-0.009	-0.015	-0.241	0.182	-0.069
Node number 1st female flower appearance	0.024	**0.055**	-0.013	-0.014	-0.008	-0.245	0.182	-0.019
Days to first edible fruit harvest	0.136	0.005	**-0.139**	-0.013	-0.006	-0.277	0.179	-0.115
Fruit length (cm)	0.013	0.008	-0.018	**-0.096**	0.085	-0.203	0.303	0.09
Fruit diameter (cm)	0.019	0.004	-0.008	0.075	**-0.108**	0.082	-0.032	0.032
Number of fruits per plant	-0.034	-0.014	0.039	0.02	-0.009	**0.974**	-0.281	0.696**
Fruit weight (kg)	0.034	0.013	-0.033	-0.039	0.005	-0.364	**0.751**	0.368**

Residual effect = 0.053, and *P<0.05, **P<0.01, respectively.

Table 4.1.8: Phenotypic path analysis showing direct and indirect effects of traits on yield per plant in bottle gourd in optimum season

Traits	Days to first female appearance	Node number 1st female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Fruit weight (kg)	Yield per Plant (kg)
Days to first female appearance	**0.132**	0.009	-0.116	-0.008	-0.013	-0.206	0.171	-0.063
Node number 1st female flower appearance	0.021	**0.057**	-0.011	-0.011	-0.007	-0.206	0.158	-0.022
Days to first edible fruit harvest	0.125	0.005	**-0.122**	-0.011	-0.006	-0.231	0.167	-0.107
Fruit length (cm)	0.013	0.007	-0.016	**-0.087**	0.078	-0.175	0.281	0.089
Fruit diameter (cm)	0.017	0.004	-0.007	0.066	**-0.102**	0.064	-0.028	0.034
Number of fruits per plant	-0.03	-0.013	0.031	0.017	-0.007	**0.912**	-0.247	0.662**
Fruit weight (kg)	0.032	0.013	-0.029	-0.035	0.004	-0.32	**0.703**	0.358**

Residual effects= 0.0622, and *p≤0.05, **p≤0.01 level of probability.

Table 4.1.9: Summary path analysis for direct effects of different traits on yield per plant in bottle gourd under optimum conditions

Traits	Genotypic Direct Effect	Phenotypic Direct Effect	Correlation with Yield (rg)	Correlation with Yield (rp)	Nature of Association	Relative Contribution to Yield
Days to first female appearance	+0.140	+0.132	-0.069	-0.063	Weak negative, indirect via number of fruits and fruit weight	Minor, indirect contributor (earliness desirable)
Node number of 1st female flower appearance	+0.055	+0.057	-0.019	-0.022	Weak negative, indirect via number of fruits	Lower node flowering desirable
Days to first edible fruit harvest (DH)	-0.139	-0.122	-0.115	-0.107	Negative, direct and indirect via number of fruits	Early maturity beneficial
Fruit length (FL)	-0.096	–0.087	+0.090	+0.089	Slight positive total due to indirect via fruit weight	Moderate fruit length beneficial
Fruit diameter (FD)	-0.108	–0.102	+0.032	+0.034	Very weak, negligible	Limited role; maintain balanced shape
Number of fruits per plant (NFP)	+0.974	+0.912	+0.696	+0.662	Strong positive	Most important yield component
Fruit weight (FW)	+0.751	+0.703	+0.368	+0.358	Strong positive	Major direct contributor to yield

Table 4.1.10: Combined summary of genotypic and phenotypic path analysis for yield per plant in bottle gourd under optimum conditions

Traits	Correlation with yield per plant	Genotypic path analysis					Phenotypic path analysis					
		Direct Effect (G)	Positively acting indirect traits		Negative indirect		Correlation with yield per plant	Direct Effect (P)	Positively acting indirect traits		Negative indirect	
			Value	No. traits	Value	No. traits			Value	No. traits	Value	No. traits
Days to first female appearance (DFF)	-0.069	0.14	0.191	2	-0.401	4	-0.063	0.132	0.171	2	-0.206	3
Node no. of 1st female flower (NFF)	-0.019	0.055	0.206	2	-0.280	4	-0.022	0.057	0.158	1	-0.206	2
Days to first edible fruit harvest (DH)	-0.115	-0.139	0.32	3	-0.296	3	-0.107	-0.122	0.167	1	-0.231	2
Fruit length (FL)	0.09	-0.096	0.409	4	-0.221	2	0.089	-0.087	0.281	1	-0.175	1
Fruit diameter (FD)	0.032	-0.108	0.18	4	-0.040	2	0.034	-0.102	0.064	1	-0.028	1
Number of fruits per plant (NFP)	0.696	0.974	0.059	2	-0.338	4	0.662	0.912	0.017	1	-0.247	1
Fruit weight (FW)	0.368	0.751	0.052	3	-0.436	3	0.358	0.703	0.032	2	-0.320	1

Fruit weight also exhibited the second highest positive direct effect on yield at both genotypic (0.751) and phenotypic (0.703) levels. This trait featured a strong positive correlation with yield per plant (genotypic r = 0.368; phenotypic r = 0.358). It further showed indirect positive effects through fruit length (0.303, 0.281) and negative indirect effects on the number of fruits per plant (-0.281, -0.247). This confirmed that fruit weight was another major determinant of yield, and improvement in fruit weight would directly increase yield per plant. Sree *et al.* (2019) reported that fruit weight showed positive direct effect on fruit yield (0.401) and positive indirect effect on fruit yield via fruit girth (0.029). Kumar *et al.* (2020a) reported that average fruit weight showed a significant positive correlation (0.945) with yield/plot. It had positive direct effect on yield/plot (0.567) but an indirect effect on yield/plot via vine length (-0.404), number of primary branches per vine (0.203), number of nodes per vine (-0.528), days to first harvesting (-0.342), fruit length (0.560), and fruit girth (0.537). Singh *et al.* (2022) and Bashir *et al.* (2024) also reported similar results, which correspond to the present investigations.

Path coefficient analyses across studies consistently identified average fruit weight, number of fruits per plant, fruit diameter, and flowering-related traits as the major contributors to fruit yield in bottle gourd. Kunjam *et al.* (2019) reported strong positive direct effects of average fruit weight (2.96), node at first female flower (2.76), days to first female flower (1.06), and fruit girth (0.23), suggesting direct selection for heavier and larger fruits. Similarly, Sree *et al.* (2019) observed high positive direct effects of number of fruits per vine (0.8454), average fruit weight (0.4014), fruit girth (0.7287), and node at first female flower (0.3820), while fruit length showed a negative direct effect. Sultana *et al.* (2018) also reported the highest positive direct effect of number of fruits per plant (0.93), followed by fruit weight (0.467), indicating these as key selection criteria. Muralidharan *et al.* (2017) further confirmed positive direct effects of fruit weight (1.33) and fruit width (0.72) on yield. These findings emphasized that selection for early flowering, higher fruit number, and increased fruit weight and diameter was most effective for yield improvement, which was in close agreement with the results of the present study.

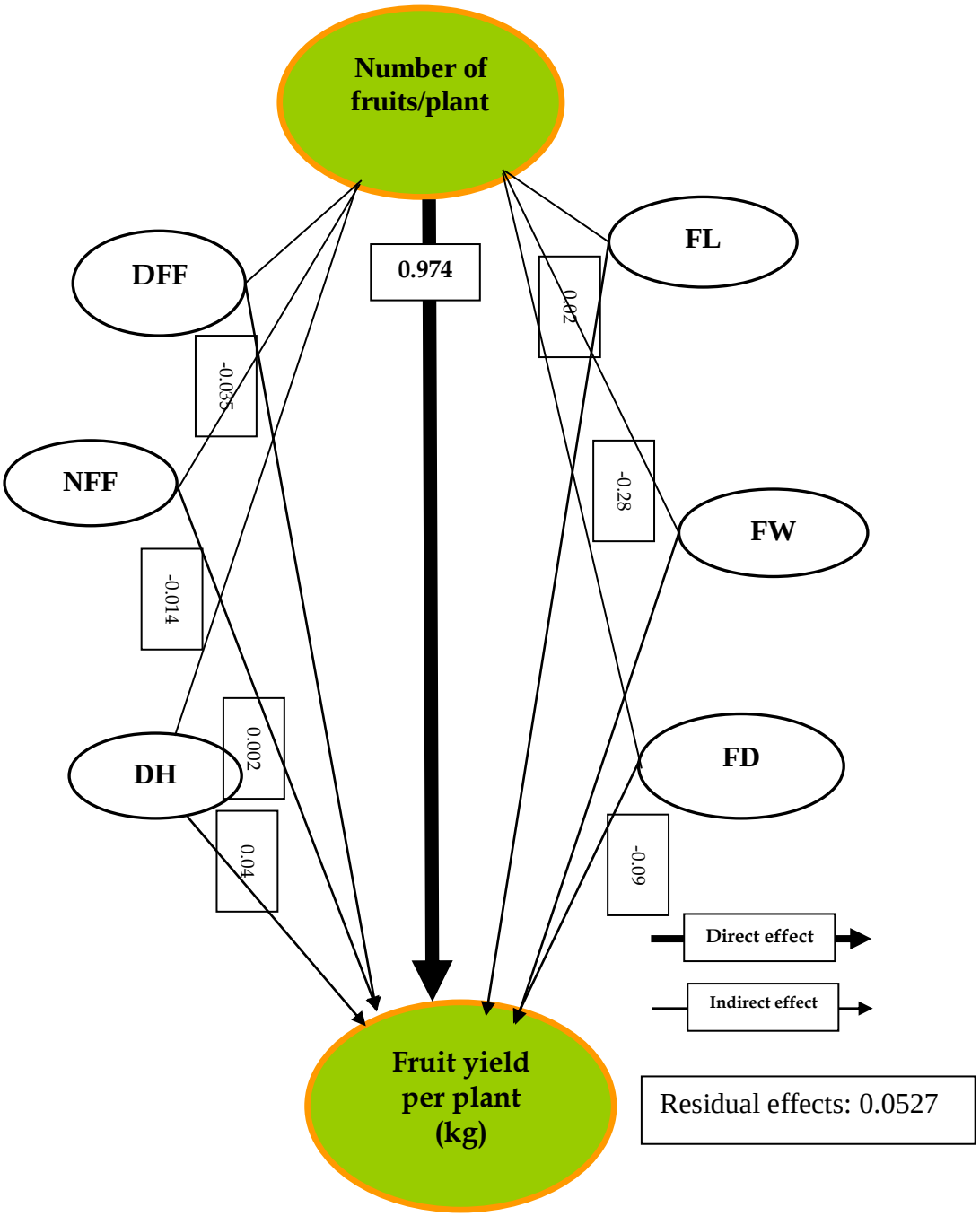


Figure 4.1.1: Showing Genotypic direct and indirect effect of number of fruits per plant on yield per plant in bottle gourd under optimum sowing conditions

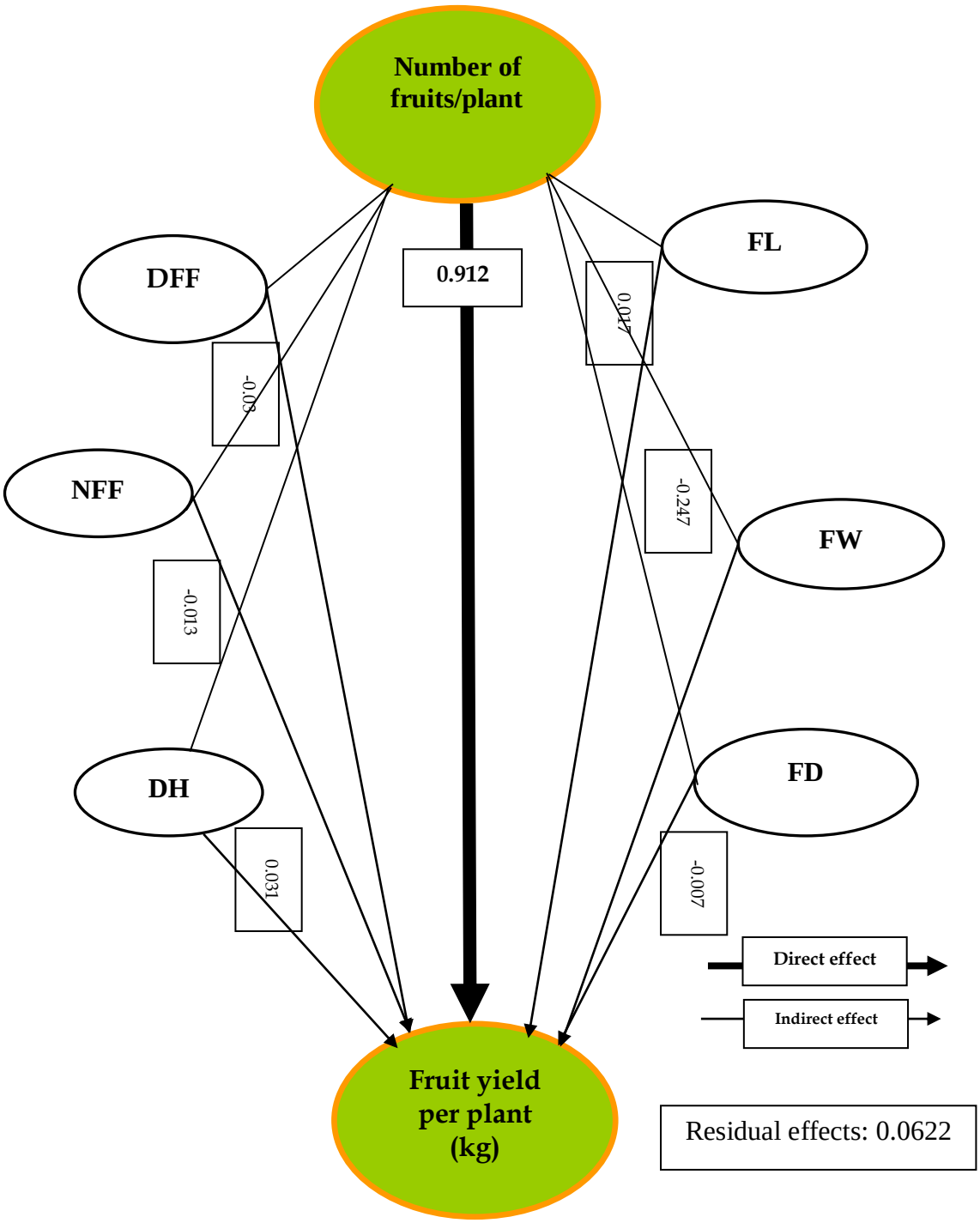


Figure 4.1.2: Showing Phenotypic direct and indirect effect of number of fruits per plant on yield per plant in bottle gourd under optimum sowing conditions

4.1.5 Correlations among yield and its component traits under heat-stress conditions

The correlation analysis revealed that most of the traits showed a similar pattern of association at both genotypic and phenotypic levels, although the genotypic correlations were generally of higher magnitude, indicating a strong inherent genetic relationship among the traits. The magnitude of genotypic correlation coefficients was greater than that of phenotypic correlation coefficients. This suggested that there was a strong underlying genotypic connection between the characteristics investigated, despite the fact that phenotypic manifestation was hampered by environmental factors. Phenotypic and genotypic correlation coefficients between yield and yield-contributing components of bottle gourd are presented in Table 4.1.9.

Days to first female flower appearance

Days to first female flower appearance exhibited a highly significant positive genotypic correlation with days to first edible fruit harvest (0.954) and node number at which the first female flower appeared (0.375). However, it was negatively correlated with fruit length (–0.078) and yield per plant (–0.263). The corresponding phenotypic correlations were similar in direction but of smaller magnitude, with a strong positive correlation with days to first edible fruit harvest (0.973) and a significant negative association with number of fruits per plant (-0.247). This suggested that delayed female flowering tends to delay fruit maturity and reduce yield under heat stress. Such above associations also reported by Deepthi *et al.* (2016) and Kumari *et al.* (2021). Deepthi *et al.* (2016) exhibited that days to appearance of 1st female flower appearance had shown significant negative association with number of fruits per vine and yield per vine indicating that delayed female flower appearance will have negative effect on fruit number and yield per vine.

Node number at first female flower appearance

Node number at first female flower appearance showed a significant positive genotypic correlation with days to first edible fruit harvest (0.475) and a moderate positive association with fruit length (0.266). This trait exhibited negative correlations with number of fruits per plant (-0.311), fruit diameter (-0.156), and yield per plant (-0.185). In the case of the phenotypic level, it correlated positively with fruit weight (0.243) and fruit length (0.144) and negatively associated with the number of fruits per plant (-0.252). These results indicated that higher node numbers delayed flowering and reduced fruiting efficiency.

Days to first edible fruit harvest

Days to first edible fruit harvest had strong positive genotypic associations with days to first female flower appearance (0.954) and node number at first female flower appearance (0.475), confirming their close relationship among the phenological traits. It showed significant negative correlations with fruit length (-0.411) and yield per plant (-0.251), implying that delayed harvest reduced yield potential. The phenotypic relationships followed the same trend, with significant negative association with number of fruits per plant (-0.285) and yield (-0.115). Kumari *et al.* (2021) showed that days to first harvesting showed a highly significant and negative correlation with of fruit per vine (rp = -0.784) and yield per plot (rp = -0.804) and negative and significant correlation with fruit girth (rp = 0.633) which was in line with the current findings.

Fruit length

Fruit length showed a significant negative genotypic correlation with fruit diameter (-0.808) and a moderate negative correlation with yield per plant (-0.199) and number of fruits per plant (-0.277), while being positively associated with fruit weight (0.154). At the phenotypic level, fruit length was negatively correlated with fruit diameter (-0.777) and number of fruits per plant (–0.208) but positively correlated with fruit weight (0.403). This indicated that longer fruits tend to have reduced diameter and number of fruits but higher individual weight. Kumari *et al.* (2021) revealed that fruit length showed highly significant and positive correlation with fruit girth (rp = 0.992), average fruit weight (rp = 0.987) and yield per plot (rp = 0.699). These results were in contrast with the findings of the present investigations.

Fruit diameter

Fruit diameter was positively correlated with the number of fruits per plant (0.357) and yield per plant (0.434). A similar positive relationship was also observed at the phenotypic level, but at a smaller level for yield (0.032) and number of fruits per plant (0.084). The positive correlation of fruit diameter with yield shows that thicker fruits contribute more to overall productivity under heat stress. Kumari *et al.* (2021) estimated path analysis for fruit girth showed highly significant and positive correlation with average fruit weight (rp = 0.947) and positive and significant correlation with yield per plot (rp = 0.711). These results were similar to the findings of the present study.

Table 4.1.11: Genotypic and phenotypic correlation coefficients among eight characters of bottle gourd under Heat stress conditions

Traits		Days to first female appearance	Node number 1st female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Fruit weight (kg)	Yield per Plant (kg)
Days to first female appearance	G	1	0.375**	0.954**	-0.078	-0.005	-0.437**	-0.071	-0.263**
	P		0.169*	0.973**	0.095	0.136	-0.247**	0.243**	-0.069
Node number 1st female flower appearance	G		1	0.475**	0.266**	-0.156	-0.311**	0.116	-0.185*
	P			0.096	0.144	0.076	-0.252**	0.243**	-0.019
Days to first edible fruit harvest	G			1	-0.011	-0.065	-0.411**	-0.089	-0.251**
	P				0.130	0.060	-0.285**	0.238**	-0.115
Fruit length (cm)	G				1	-0.808**	-0.227*	0.154	-0.199*
	P					-0.777**	-0.208**	0.403**	0.090
Fruit diameter (cm)	G					1	0.357**	0.188*	0.434**
	P						0.084	-0.042	0.032
Number of fruits per plant	G						1	-0.071	0.807**
	P							-0.373**	0.696**
Fruit weight (kg)	G							1	0.354**
	P								0.368**

Here, G = Genotypic correlation, P = Phenotypic correlation, *P < 0.05, and **P < 0.01, respectively.

Number of fruits per plant

The number of fruits per plant exhibited a highly significant positive correlation with yield per plant at both genotypic (r = 0.807) and phenotypic (r = 0.696) levels, identifying it as the most influential yield component. However, fruit number showed a weak negative association with fruit weight at the genotypic level (r = −0.071) and a moderate negative association at the phenotypic level (r = −0.373), indicating a compensatory relationship between fruit number and individual fruit size. In contrast, Husna *et al.* (2011) reported positive correlations between fruit number and fruit weight at both genotypic (r = 0.474) and phenotypic (r = 0.388) levels. Furthermore, Kumari *et al.* (2021) observed a highly significant positive correlation of number of fruits per vine with yield per plot (rp = 0.952), strongly supported the present findings on the importance of fruit number in determining yield.

Fruit weight

Fruit weight showed a significant positive association with yield per plant at both genotypic (r = 0.354) and phenotypic (r = 0.368) levels, highlighting its key role in yield improvement. Its positive correlation with fruit length (r = 0.154 and 0.403) suggested that heavier fruits were generally longer. These findings were consistent with Kumari *et al.* (2021), reported a strong positive relationship between average fruit weight and yield per plot (rp = 0.775) during the kharif season, thereby supported the present results.

Yield per plant

Yield per plant showed strong positive genotypic correlations with number of fruits per plant (r = 0.807), fruit diameter (r = 0.434), and fruit weight (r = 0.354), while negative associations were observed with days to first female flower appearance (r = −0.263) and days to first edible fruit harvest (r = −0.251). Similar trends were evident at the phenotypic level (except for fruit diameter), indicating that higher fruit number, larger fruit size, and greater fruit weight are the key determinants of yield, even under heat-stress conditions. These findings were in close agreement with earlier reports by Deepthi *et al.* (2016), Mahapatra *et al.* (2019), and Bashir *et al.* (2024) across kharif and summer seasons, which also emphasized the yield advantage of early female flowering. Abhishek *et al.* (2020) reported strong positive associations of fruit yield per plant with fruit yield per plot (r =

0.988 P; 1.003 G) and number of fruits per plot (r = 0.233 P; 0.927 G), while fruit number was negatively correlated with days to male (r = −0.382 G) and female flowering (r = −0.253 G). Likewise, Bashir *et al.* (2024) observed significant positive correlations of yield with fruit yield per plant (rp = 0.99, rg = 0.98), fruit weight (r = 0.82), the number of fruits per plant (r = 0.38), and fruit diameter (r = 0.30). In both studies, genotypic correlations exceeded phenotypic ones, indicating strong genetic control. These results confirmed that number of fruits per plant, fruit weight, and fruit diameter were key selection traits for improving bottle gourd yield under heat-stress conditions.

4.1.6 Path analysis for yield per plant under heat-stress conditions

Path coefficient analysis was carried out using genotypic correlations to determine the direct and indirect effects of yield-contributing traits on yield per plant under heat-stress conditions. The residual effects were 0.154 at genotypic levels, indicating that the included traits accounted for about 84.6% of the total variation in yield per plant. Hence, the path model efficiently explained most of the variability in yield. The path coefficients at genotypic level are presented in Table 4.1.12 and depicted in Figure 4.1.3.

At the genotypic level, days to first female flower appearance showed a very low positive direct effect on yield per plant (0.058) but exerted a strong negative indirect effect through number of fruits per plant (–0.392), resulting in an overall negative correlation with yield (r = –0.263). This indicated that delayed female flowering ultimately reduces yield by lowering fruit number. Node number at first female flower appearance had a negative direct effect on yield (–0.014), with additional negative indirect effects via number of fruits per plant (–0.279), leading to a negative total association with yield (r = –0.185). This suggested that appearance of the first female flower at higher nodes were associated with delayed and reduced productivity, in agreement with Varalakshmi *et al.* (2018).

Similarly, days to first edible fruit harvest showed a moderate positive direct effect (0.106) but strong negative indirect effects through number of fruits per plant (–0.368), resulting in an overall negative association with yield (r = –0.251). These results emphasized that earlier female flowering and earlier fruit harvest favor higher yield mainly through increased fruit number.

Fruit length had negative direct effects on yield (-0.079) at genotypic levels. Conversely, it contributed indirectly and positively through fruit diameter (0.023) and fruit weight (0.069). The total correlation with yield was at a very low level (-0.199). This indicated longer fruits slightly improve individual fruit weight; but not significantly increase total yield. Fruit diameter had a low negative direct effect (-0.029) but a positive indirect effect through number of fruits per plant (0.320) and fruit weight (0.085). The total association of fruit diameter with yield per plant was positive (0.434). Therefore, the indirect influence of fruit diameter via number of fruits per plant and fruit weight contributed more to yield improvement than its direct effect.

Number of fruits per plant had the highest positive direct effect (0.896) on yield at genotypic levels. It also exerted positive indirect effects on fruit length (0.018) and negative indirect effects on fruit weight (-0.032). The strong positive total correlation with yield (0.807) clearly indicated that this trait was the most important component directly contributing to yield per plant under heat-stress conditions. Similarly, Varalakshmi *et al.* (2018) and Husna *et al.* (2011) also reported that fruit traits had maximum direct effect on fruit yield in bottle gourd. Mahapatra *et al.* (2019) revealed number of fruits per plant had a positive direct effect on fruit yield per plant. It also contributed indirectly in a positive direction through days to opening of first female flower (0.0003), fruit length (0.0038), fruit diameter (0.0170), and negative effect with days to first fruit harvest (-0.0010) and average fruit weight (-0.5695) on fruit yield per plant which were identical with the findings of the present study.

Fruit weight showed a moderate direct positive effect on yield (0.450) at genotypic levels. There were negative indirect effects of fruit weight through fruit length (-0.012), and the number of fruits per plant (-0.064) was recorded for fruit weight. The total correlations for fruit yield per plant (0.354) were positive, confirming its key role in determining fruit yield per plant. Thus, heavier fruits significantly enhance yield even when the number of fruits was lower.

Path coefficient studies consistently identified number of fruits per plant, fruit weight, and fruit diameter as the major direct contributors to yield in bottle gourd. Varalakshmi *et al.* (2018) reported the highest direct effect of number of fruits on yield (0.812), followed by fruit weight (0.407), fruit length (0.339), and fruit width (0.310) under off-season conditions. Abhishek *et al.* (2020), however, observed positive direct effects of fruit yield

Table 4.1.12: Genotypic path analysis showing direct and indirect effects of traits on yield per plant in bottle gourd under heat stress condition

Traits	Days to first female appearance	Node number first female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Number of fruits per plant	Fruit weight (kg)	Yield per Plant (kg)
Days to first female appearance	**0.058**	-0.005	0.101	0.006	-0.001	-0.392	-0.032	-0.263
Node number first female appearance	0.022	**-0.014**	0.05	-0.021	0.005	-0.279	0.052	-0.185
Days to first edible fruit harvest	0.055	-0.007	**0.106**	0.001	0.002	-0.368	-0.04	-0.251
Fruit length (cm)	-0.005	-0.004	-0.001	**-0.079**	0.023	-0.203	0.069	-0.199
Fruit diameter (cm	0.001	0.002	-0.007	0.064	**-0.029**	0.32	0.085	0.434**
Number of fruits per plant	-0.025	0.004	-0.044	0.018	-0.01	**0.896**	-0.032	0.807**
Fruit weight (kg)	-0.004	-0.002	-0.009	-0.012	-0.005	-0.064	**0.45**	0.354**

Residual effect = 0.154, *p≤0.05 and **p≤0.01 level of probability.

per plot (1.014), number of branches (0.174), and number of nodes (0.050) during the kharif season, indicated some seasonal variation in key traits. In contrast, Bashir *et al.* (2024) reported strong positive direct effects of fruit yield per plant (0.78), fruit weight (0.502), number of primary branches (0.401), number of fruits per plant (0.218), and fruit diameter (0.214), while flowering-delay traits had negative direct effects. These results, together with Mahapatra *et al.* (2019), who emphasized fruit number, fruit diameter, and average fruit weight for genetic gain, strongly support the present findings. The selection for higher fruit number, greater fruit weight, and larger fruit diameter emerged as the most reliable strategy for yield improvement in bottle gourd.

Considering the overall effects, the number of fruits per plant, fruit weight and fruit diameter exhibited the most positive and direct contributions to yield per plant under heat stress. In contrast, days to first female flower appearance and days to first edible fruit harvest showed negative effects, indicating that earliness in flowering and fruit setting was desirable for higher yield performance in heat-stress conditions.

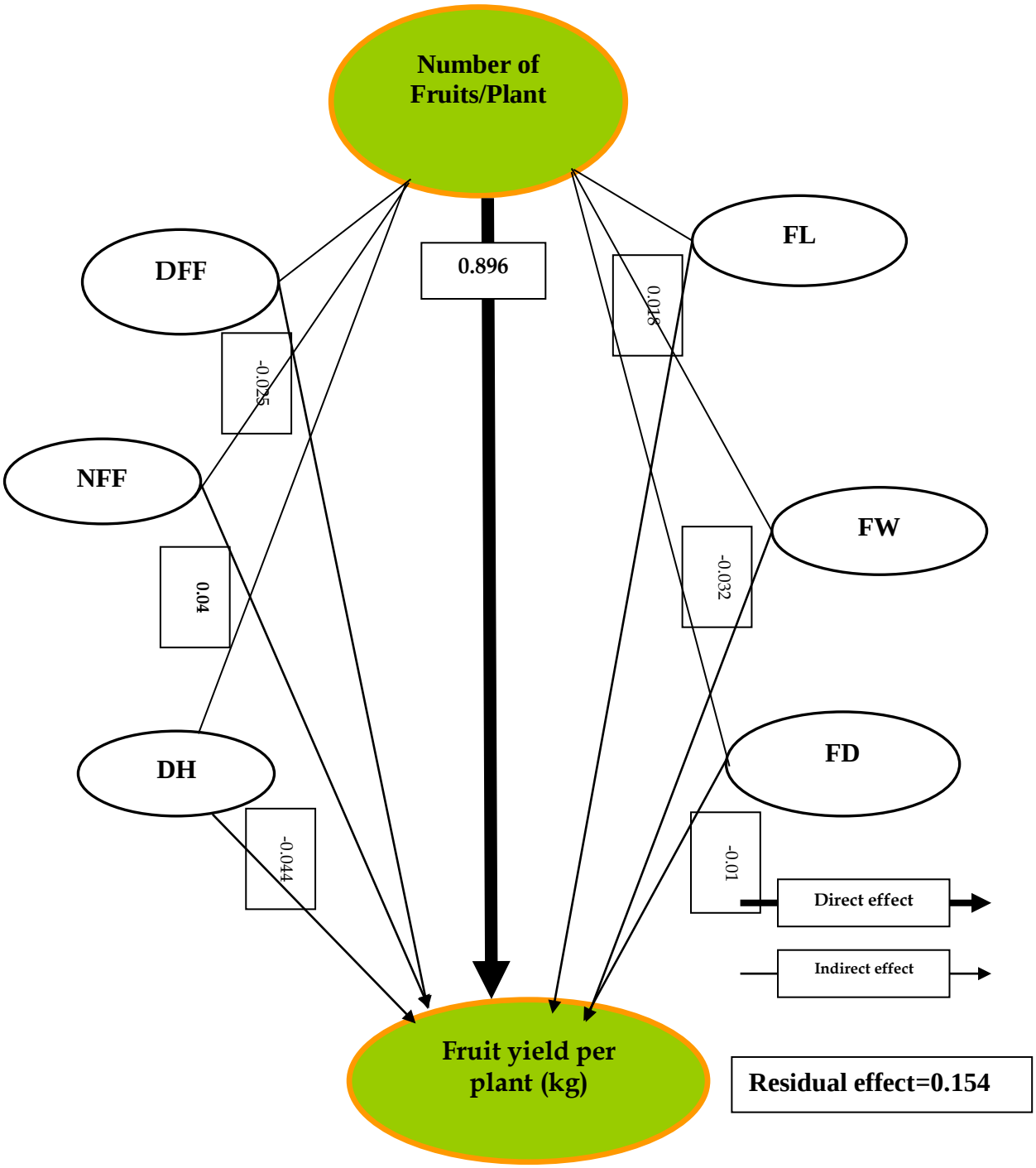


Figure 4.1.3: Showing Genotypic direct and indirect effect of number of fruits on yield per plant in bottle gourd under heat stress



Plate 4.1.1: Fruit morphotypes of fifty-eight (58) genotypes evaluated by supervisory committee

4.2 Experiment-II. Screening and Identification of Heat-Tolerant Bottle Gourd Genotypes Using Stress Tolerance Indices

The identification of heat-tolerant lines requires reliable selection criteria capable of distinguishing genotypes that maintain stable performance under elevated temperature conditions. Several stress tolerance indices have been widely employed to quantify genotype responses to environmental stress. Among these, the Tolerance Index (TOL) measures the reduction in yield under stress compared with optimal conditions, while the Mean Productivity (MP) reflects the average performance of a genotype across both environments. The Stress Tolerance Index (STI), proposed to differentiate high-yielding and stress-tolerant genotypes, has proven particularly useful for identifying superior cultivars under both non-stress and stress conditions. In addition, indices such as the Geometric Mean Productivity (GMP), Yield Stability Index (YSI), Yield Index (YI), and Harmonic Mean (HM) provide robust estimates of yield stability and adaptability under variable environments. Conversely, low values of indices associated with yield loss, such as TOL, Stress Susceptibility Index (SSI), and yield reduction percentage, are desirable indicators of tolerance.

Based on the results of the correlation and path coefficient analyses conducted in experiment 1, three key yield-determining traits, like fruit diameter, number of fruits per plant, and fruit weight, were identified as the major contributors to total yield in bottle gourd. These traits exhibited strong positive associations with yield, indicating their pivotal role in determining productivity under varying environmental conditions. Considering the strong positive influence of these traits on yield performance, they were used in the subsequent evaluation of heat stress tolerance. Building upon these findings, this section integrates overall yield with key yield-contributing traits using multiple heat stress tolerance indices to screen and select superior genotypes. In the present investigation, bottle gourd genotypes were evaluated under optimum and high-temperature conditions to determine their relative performance based on yield and its key components and their associated stress tolerance indices.

4.2.1 Fruit diameter-based heat stress tolerance indices

4.2.1.1 Stress tolerance indices

Fruit diameter is an important yield determinant in bottle gourd and is often used as an indirect indicator of fruit marketability and consumer preference. In the present study, fruit

diameter (FD) was significantly influenced by high temperature, as reflected by the marked reduction in under heat stress (FDhs) compared to optimum conditions (FDns) among the tested genotypes (Table 4.2.1). Although several genotypes maintained comparable or very low reduction in fruit diameter across both environments, many of the genotypes exhibited substantial shrinkage in fruit diameter under heat stress, demonstrated the sensitivity of fruit growth processes to elevated temperature.

Stress tolerance indices like Tolerance index (TOL), Mean productivity (MP), Geometric mean productivity (GMP), Harmonic mean (HM), Stress susceptibility index (SSI), Stress tolerance index (STI), Yield index (YI), Yield stability index (YSI), and Relative stress index (RSI) were estimated based on fruit diameter (Table 4.2.2). Under optimum temperature conditions, fruit diameter ranged from 7.97 cm (BG-06) to 20.82 cm (BG-29), whereas under heat stress, FDhs ranged between 0.00 cm and 16.55 cm (BG-57). These drastic reduction or complete absence of fruit diameter in heat stress (FDhs) in several genotypes strongly indicated abortion of young fruits or suppressed ovary development under high temperature, similarly emphasized by Saroj and Chaudhary (2020), and Mashilo (2016) in cucurbits.

Highly tolerant genotypes for fruit diameter exhibited low stress susceptibility index (SSI ≤ 0.30) and high YSI (≥ 0.90), sustained fruit diameter under heat stress (FDhs) nearly close to fruit diameter under optimum (FDns) conditions. Among the studied fifty-eight genotypes, BG-35, BG-36, BG-37, BG-38, BG-39, BG-41, BG-42, BG-45, BG-55, BG-56, BG-57, and BG-58 exhibited minimal percentage reduction, lower Stress Susceptibility Index (SSI), and relatively higher YSI and RSI values, indicated their superior ability to retain fruit diameter under heat stress. According to Fernandez (1992), a combination of high GMP, HM, and STI values strongly explained stable yield potential under both optimum and stress environments. These indices were consistently high in BG-35, BG-37, BG-39, BG-42, BG-54, BG-55, and BG-57, confirming their heat tolerance in terms of fruit diameter under heat stress conditions. Conversely, among the fifty-eight genotypes, nineteen, including BG-04, BG-09, BG-11, BG-13, BG-14, BG-15, BG-22, BG-23, BG-25, BG-26, BG-27, BG-29, BG-30, and BG-31, were recorded with zero or no fruit or fruit diameter (FDhs) under heat stress and exhibited extremely higher TOL and SSI values, which indicated their extreme susceptibility to heat stress.

Table 4.2.1: Performance of genotypes in optimum vs. heat stress environments and reduction (%) for yield and its key components

Genotypes	Fruit diameter (cm)			Number of fruits per plant			Fruit weight (kg)			Yield (t ha^{-1})		
	Optimum	Heat stress	% Red.	Optimum	Heat stress	% Red.	Optimum	Heat stress	% Red.	Optimum	Heat stress	% Red.
BG-01	10.88 r–w	10.19m–o	6.34	11.97 c–e	9.61 d–f	19.70	1.93 o–r	1.59k–m	17.62	45.94 e–g	33.65 d	26.75
BG-02	11.60 n–q	10.62 k–n	8.45	12.10 c–e	10.78 cd	10.91	2.16 h–i	1.86 b	13.89	51.25 a–c	40.73 a	20.53
BG-03	11.62 n–q	10.24 l–o	11.88	12.57 c	6.33 kl	49.63	1.73 u–w	1.18 t–u	31.79	42.33 i–k	23.59 h–i	44.27
BG-04	11.58 n–r	0	100.00	11.87 c–e	0	100.00	1.94 o–q	0	100.00	45.56 f–g	0	100.00
BG-05	16.49 d–e	15.22 b–d	7.70	8.10 l–p	6.00 lm	25.93	1.73 u–w	1.40 q–r	19.08	36.66 p–s	27.56 g	24.82
BG-06	7.97 y	6.04 u	24.22	8.57 j–n	7.39 jk	13.74	1.23 b	1.03 w	16.26	21.12 f	11.35 p	46.26
BG-07	11.43 o–r	10.46 k–o	8.49	9.93 g–j	8.89 e–h	10.50	1.92 q–r	1.48 o–p	22.92	37.88 o–r	27.53 g	27.32
BG-08	13.63 h–i	11.70 i	14.16	9.33 h–l	8.67 f–i	7.10	1.76 u–v	1.59 k–n	9.66	31.52 v–x	21.06 j–l	33.19
BG-09	11.53 o–r	0	100.00	8.33 k–o	0	100.00	1.78 t–u	0	100.00	27.50 z–b	0	100.00
BG-10	15.93 e–f	14.35 f–g	9.92	6.00 r–s	5.33 l–o	11.17	2.16 h–i	1.77 d–e	18.06	26.54 a–c	19.38l–m	26.98
BG-11	15.00 g	0	100.00	6.00 r–s	0	100.00	2.00 l–p	0	100.00	23.70 d–f	0	100.00
BG-12	13.07 i–k	10.97 j–k	16.07	6.33 q–s	4.33 o–q	31.63	2.33 c–d	1.71 f–h	26.61	28.39 y–a	16.88 n	40.54
BG-13	11.70 n–q	0	100.00	10.33 f–i	0	100.00	2.34 c–d	0	100.00	50.73 b–d	0	100.00
BG-14	11.68 n–q	0	100.00	6.33 q–s	0	100.00	2.20 f–h	0	100.00	28.79 y–a	0	100.00
BG-15	13.93 h	0	100.00	5.67 s	0	100.00	2.24 e–f	0	100.00	27.24 z–c	0	100.00
BG-16	11.47 o–r	10.27 k–o	10.46	8.67 j–n	8.33 g–j	3.89	2.17 g–i	1.63 i–l	24.88	41.22 j–m	28.26 f–g	31.44
BG-17	11.62 n–q	10.38 k–o	10.67	10.67 e–h	8.33 g–j	21.91	1.64 x–y	1.21 t–u	26.22	35.55 q–s	24.65 h	30.66
BG-18	10.22w–x	8.63 r	15.56	9.67 g–k	9.46 e–g	2.14	1.57 y	1.35 r–s	14.01	27.91 y–b	25.06 h	10.21
BG-19	11.37 p–s	6.78 t	40.37	7.33 n–r	4.67 n–q	36.32	1.69 v–x	1.43 p–q	15.38	25.50 b–e	12.33 p	51.65
BG-20	16.43 e	0	100.00	9.00 i–m	0	100.00	1.39 z–a	0	100.00	23.36 e–f	0	100.00

Note: Means followed by the same letter(s) within a column are not significantly different at the 5% probability level according to Duncan's Multiple Range Test (DMRT). Means with different letter(s) indicate significant differences ($P \leq 0.05$).

Table 4.2.1: Performance of genotypes in optimum vs. heat stress environments and reduction (%) for yield and its key components (cont'd)

Genotypes	Fruit Diameter(cm)			Number of fruits per plant			Fruit weight(kg)			Yield (t ha^{-1})		
	Optimum	Heat stress	% Red	Optimum	Heat stress	% Red	Optimum	Heat stress	% Red	Optimum	Heat stress	% Red
BG-21	12.02m–p	10.83k–m	9.90	8.67 j–n	7.67 ij	11.50	2.21 f–h	1.85 b–c	16.29	39.27 l–p	28.54 f–g	27.32
BG-22	10.90 r–w	0	100.00	9.67 g–k	0	100.00	1.88 q–s	0	100.00	35.31 r–t	0	100.00
BG-23	9.88 x	0	100.00	7.00 o–r	0	100.00	2.02 k–m	0	100.00	27.25 z–c	0	100.00
BG-24	12.12 l–o	9.70 p–q	19.97	11.00 d–g	5.33 l–o	51.55	2.29 d–e	1.59k–m	30.57	50.90 b–c	16.85 n	66.90
BG-25	10.48 u–x	0	100.00	7.67 m–q	0	100.00	1.46 z	0	100.00	24.68 c–e	0	100.00
BG-26	11.18 q–u	0	100.00	10.00 g–j	0	100.00	2.52 b	0	100.00	48.12 d–f	0	100.00
BG-27	11.40 p–r	0	100.00	7.33 n–r	0	100.00	2.09 j–k	0	100.00	29.62 w–z	0	100.00
BG-28	11.13 q–v	9.20 q–r	17.34	9.33 h–l	8.67 f–i	7.10	2.18 f–h	1.94 a	11.01	38.89 m–p	32.98 d	15.20
BG-29	20.82 a	0	100.00	9.33 h–l	0	100.00	2.23 e–g	0	100.00	38.21 n–q	0	100.00
BG-30	11.95m–p	0	100.00	8.33 k–o	0	100.00	2.22 e–h	0	100.00	38.07 n–q	0	100.00
BG-31	15.23 f–g	0	100.00	8.00 l–p	0	100.00	2.04 j–m	0	100.00	35.17 r–t	0	100.00
BG-32	12.12 l–o	10.15m–o	16.25	7.33 n–r	4.00 pq	45.45	2.05 j–m	1.59k–m	22.44	29.85 w–z	14.27 o	52.19
BG-33	13.17 i–k	0	100.00	10.00 g–j	0	100.00	1.43 z	0	100.00	23.55 e–f	0	100.00
BG-34	10.47 v–x	7.53 s	28.08	6.67 p–r	3.67 q	44.95	1.99 m–p	1.41 q–r	29.15	26.38 a–d	11.29 p	57.20
BG-35	13.32 h–j	12.55 h	5.78	11.67 c–f	11.03 cd	5.46	1.36 a	1.22 t–u	10.29	32.46 u–w	29.09 e–g	10.38
BG-36	12.75 j–l	12.45 h	2.35	10.00 g–j	9.28 e–h	7.20	1.94 n–q	1.72 e–g	11.34	40.67 j–n	33.14 d	18.51
BG-37	16.43 e	15.17 b–e	7.67	11.67 c–f	9.67 d–f	17.12	1.83 s–t	1.65 h–k	9.84	45.18 g–h	33.73 d	25.34
BG-38	10.65 t–w	9.85 o–q	7.51	11.00 d–g	6.33 kl	42.45	2.06 j–l	1.73 d–f	16.02	44.22 g–i	20.46 j–m	53.73
BG-39	12.58k–m	12.23 i	2.78	11.67 c–f	10.00 de	14.29	1.84 s–t	1.79 c–d	2.72	39.36 l–p	34.75 d	11.71
BG-40	17.87 b–c	15.63 b–c	12.53	10.33 f–i	6.33 kl	38.74	2.10 i–j	1.37 r–s	34.76	41.45 j–m	19.13 m	53.85

Table 4.2.1: Performance of genotypes in optimum vs. heat stress environments and reduction (%) for yield and its key components (cont'd)

Genotypes	Fruit diameter (cm)			Number of fruits per plant			Fruit weight (kg)			Yield (t ha^{-1})		
	Optimum	Heat stress	% Red	Optimum	Heat stress	% Red	Optimum	Heat stress	% Red	Optimum	Heat stress	% Red
BG-41	14.97 g	13.07 h	12.69	9.33 h–l	5.00m–p	46.43	2.01 l–n	1.53 n–o	23.88	36.73 p–s	14.51 o	60.50
BG-42	16.30 e	15.67 b–c	3.87	9.33 h–l	8.33 g–j	10.75	1.71 u–x	1.60 j–m	6.43	30.49 v–y	28.83 e–g	5.44
BG-43	12.48k–m	10.92 j–l	12.50	18.33 a	13.00 a	29.09	1.42 z–a	1.21 t–u	14.79	51.83 a–b	38.72 b	25.29
BG-44	11.32p-t	10.10 n–p	10.78	8.33 k–o	4.33 o–q	48.04	2.18 f–h	1.55mn	28.90	42.61 h–j	22.16 i–j	47.99
BG-45	14.90 g	13.90 g	6.71	11.00 d–g	9.17 e–h	16.64	2.00 l–o	1.96 a	2.00	41.87 i–l	36.71 c	12.32
BG-46	15.83 e–f	14.47 e–g	8.59	7.67 m–q	5.67 l–n	26.05	1.87 r–s	1.62 i–l	13.37	28.40 y–a	20.19k-m	28.91
BG-47	12.27 l–n	10.47 k–o	14.67	11.00 d–g	6.33 kl	42.45	1.67 w–x	1.16 u–v	30.54	39.83 k–o	20.88 j-m	47.58
BG-48	11.53 o–r	0	100.00	10.33 f–i	0	100.00	2.62 a	0	100.00	53.95 a	0	100.00
BG-49	11.12 q–v	0	100.00	9.00 i–m	0	100.00	2.20 f–h	0	100.00	40.97 j–m	0	100.00
BG-50	11.68 n–q	9.88 o–q	15.41	9.33 h–l	4.67 n–q	49.96	1.84 s–t	1.32 n–q	28.26	40.15 j–o	12.32 p	69.32
BG-51	13.05 i–k	11.57 i–j	11.34	9.67 g–k	5.33 l–o	44.86	2.37 c	1.57 l–n	33.76	45.53 f–g	21.69 j-k	52.36
BG-52	10.67 s–w	0	100.00	8.33 k–o	0	100.00	2.02 k–m	0	100.00	35.21 r–t	0	100.00
BG-53	11.77 n–q	11.68 i	3.31	13.00 c	11.67 bc	10.23	1.41 z–a	1.33 s	5.67	36.92 p–s	30.33 e	17.85
BG-54	15.70 f–g	15.23 b–d	2.87	15.00 b	11.67 bc	22.20	1.43 z–a	1.24 t	13.29	42.35 i–k	29.76 e-f	29.73
BG-55	17.19 c–d	15.87 a–b	7.68	9.67 g–k	8.33 g–j	13.83	1.67 w–x	1.48 o–p	11.38	32.75 t–v	27.76 g	15.24
BG-56	18.35 b	14.77 d–f	19.51	9.00 i–m	8.00 h–j	11.11	1.93 p–r	1.68 f–i	12.95	35.11 s–u	28 f-g	20.25
BG-57	17.18 c–d	16.55 a	3.67	12.33 c–d	10.98 cd	10.97	1.83 s–t	1.66 g–j	9.29	48.63 c–e	38.8 b	20.21
BG-58	16.48 d–e	15.12 c–e	8.25	14.67 b	12.67 ab	13.62	1.65 x	1.12 v	32.12	49.42 b–d	24.47 h	50.49
Min	7.97	0.00	2.35	5.67	0.00	2.14	1.23	0.00	2.00	21.12	0.00	5.44
Max	20.82	16.55	100.00	18.33	13.00	100.00	2.62	1.96	100.00	53.95	40.73	100.00
Mean	13.07	7.97	40.63	9.67	5.32	48.73	1.92	1.02	45.13	36.89	16.92	55.35
Std. Error (±)	0.33	0.79		0.31	0.56	5.04	0.04	0.10	5.17	1.12	1.79	4.53

These genotypes performed well under non-stress conditions but failed to produce fruits under high-temperature conditions due to complete or partial plant mortality, implying that they were suitable only for normal sowing environments. The high TOL and SSI values led to substantial yield reductions under heat stress, whereas lower values were associated with greater tolerance, which was consistent with the findings of Khan and Kabir (2014). Similar sensitivity of fruit traits to heat stress had been previously documented in other cucurbits such as pumpkin and cucumber (Saroj and Choudhary 2020, Olarewaju *et al.*, 2023).

Moreover, moderately performed genotypes retained in fruit diameter under heat stress (FDhs) between 40-75% of fruit diameter under optimum (FDns) conditions and possessed moderate SSI (0.3–0.8) values. Moderately performed tolerant cultivars such as BG-01, BG-02, BG-07, BG-08, BG-10, BG-12, BG-16, BG-17, BG-21, BG-24, BG-28, BG-32, BG-38, BG-43, BG-44, BG-47, BG-50, and BG-51 showed medium values for TOL, GMP, YSI, and SSI, indicated a balanced but not superior performance. These cultivars may serve as secondary parents in breeding programs for improving fruit diameter under heat stress.

4.2.1.2 Ranking of stress tolerance indices on fruit diameter

Evaluation of estimated stress tolerance indices (Yp, Ys, TOL, MP, GMP, HM, SSI, STI, YI, YSI, RSI) based on rank scoring revealed substantial diversity among bottle gourd genotypes in their heat tolerance. The mean rank ($\bar{R}$) and standard deviation of rank (SDR) were used to integrate multiple indicator traits to provide an effective categorization of yield stability under heat stress in Table 4.2.3.

The mean rank values ranged widely from 2.82 (BG-57) to 43.18 (BG-23), while standard deviation of rank (SDR) varied from 1.72 to 15.69. It was indicated that genotypes were reduced and impaired in yield retention capacity and stability across environments. Lower rank values accompanied by low SDR indicated consistent, strong tolerance, while high rank with higher SDR values reflected susceptibility and unstable performance. Among the evaluated genotypes, BG-57, BG-54, BG-55, BG-35, BG-36, BG-37, BG-39, BG-40, and BG-45 recorded exceptionally low stress tolerance mean ranks (≤12.50) with lower SDR, demonstrated their superior yield performance under both normal and heat stress conditions. The lowest rank values exhibited the best performer genotypes BG-57 showed the lowest $\bar{R}$ (2.82), highest stress tolerance index ranks (STI-1, YI-1, HM-1), and lowest susceptibility ranks (SSI-5).

Table 4.2.2: Fruit diameter (FD), FDns and FDhs under optimum and heat stress conditions and related stress tolerance indices of different bottle gourd genotypes

Genotype	FDns	FDhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-01	10.88	10.19	0.69	10.54	10.53	10.52	0.16	0.65	1.28	0.94	1.54
BG-02	11.60	10.62	0.98	11.11	11.10	11.09	0.21	0.72	1.34	0.92	1.51
BG-03	11.62	10.24	1.38	10.93	10.91	10.89	0.30	0.70	1.29	0.88	1.45
BG-04	11.58	0.00	11.58	5.79	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-05	16.49	15.22	1.27	15.86	15.84	15.83	0.20	1.47	1.92	0.92	1.52
BG-06	7.97	6.04	1.93	7.01	6.94	6.87	0.62	0.28	0.76	0.76	1.25
BG-07	11.43	10.46	0.97	10.95	10.93	10.92	0.22	0.70	1.32	0.92	1.51
BG-08	13.63	11.70	1.93	12.67	12.63	12.59	0.36	0.93	1.47	0.86	1.41
BG-09	11.53	0.00	11.53	5.77	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-10	15.93	14.35	1.58	15.14	15.12	15.10	0.25	1.34	1.81	0.90	1.48
BG-11	15.00	0.00	15.00	7.50	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-12	13.07	10.97	2.10	12.02	11.97	11.93	0.41	0.84	1.38	0.84	1.38
BG-13	11.70	0.00	11.70	5.85	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-14	11.68	0.00	11.68	5.84	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-15	13.93	0.00	13.93	6.97	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-16	11.47	10.27	1.20	10.87	10.85	10.84	0.27	0.69	1.29	0.90	1.48
BG-17	11.62	10.38	1.24	11.00	10.98	10.97	0.27	0.71	1.31	0.89	1.47
BG-18	10.22	8.63	1.59	9.43	9.39	9.36	0.40	0.52	1.09	0.84	1.39
BG-19	11.37	6.78	4.59	9.08	8.78	8.49	1.03	0.45	0.85	0.60	0.98
BG-20	16.43	0.00	16.43	8.22	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-21	12.02	10.83	1.19	11.43	11.41	11.39	0.25	0.76	1.37	0.90	1.49
BG-22	10.90	0.00	10.90	5.45	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-23	9.88	0.00	9.88	4.94	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-24	12.12	9.70	2.42	10.91	10.84	10.78	0.51	0.69	1.22	0.80	1.32
BG-25	10.48	0.00	10.48	5.24	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-26	11.18	0.00	11.18	5.59	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-27	11.40	0.00	11.40	5.70	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-28	11.13	9.20	1.93	10.17	10.12	10.07	0.44	0.60	1.16	0.83	1.36
BG-29	20.82	0.00	20.82	10.41	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-30	11.95	0.00	11.95	5.98	0.00	0.00	2.54	0.00	0.00	0.00	0.00

Here, FDns=Fruit diamter under non-stress and FDhas=Fruit diameter under heat stress codition

Table 4.2.2: Fruit Diameter (FD), FDns and FDhs under optimum and heat stress conditions and related stress tolerance indices of different bottle gourd genotypes (cont'd)

Genotype	FDns	FDhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-31	15.23	0.00	15.23	7.62	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-32	12.12	10.15	1.97	11.14	11.09	11.05	0.41	0.72	1.28	0.84	1.38
BG-33	13.17	0.00	13.17	6.59	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-34	10.47	7.53	2.94	9.00	8.88	8.76	0.71	0.46	0.95	0.72	1.19
BG-35	13.32	12.55	0.77	12.94	12.93	12.92	0.15	0.98	1.58	0.94	1.55
BG-36	12.75	12.45	0.30	12.60	12.60	12.60	0.06	0.93	1.57	0.98	1.61
BG-37	16.43	15.17	1.26	15.80	15.79	15.77	0.19	1.46	1.91	0.92	1.52
BG-38	10.65	9.85	0.80	10.25	10.24	10.23	0.19	0.61	1.24	0.92	1.52
BG-39	12.58	12.23	0.35	12.41	12.40	12.40	0.07	0.90	1.54	0.97	1.60
BG-40	17.87	15.63	2.24	16.75	16.71	16.68	0.32	1.63	1.97	0.87	1.44
BG-41	14.97	13.07	1.90	14.02	13.99	13.96	0.32	1.14	1.65	0.87	1.44
BG-42	16.30	15.67	0.63	15.99	15.98	15.98	0.10	1.49	1.98	0.96	1.58
BG-43	12.48	10.92	1.56	11.70	11.67	11.65	0.32	0.80	1.38	0.88	1.44
BG-44	11.32	10.10	1.22	10.71	10.69	10.68	0.27	0.67	1.27	0.89	1.47
BG-45	14.90	13.90	1.00	14.40	14.39	14.38	0.17	1.21	1.75	0.93	1.54
BG-46	15.83	14.47	1.36	15.15	15.13	15.12	0.22	1.34	1.82	0.91	1.51
BG-47	12.27	10.47	1.80	11.37	11.33	11.30	0.37	0.75	1.32	0.85	1.41
BG-48	11.53	0.00	11.53	5.77	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-49	11.12	0.00	11.12	5.56	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-50	11.68	9.88	1.80	10.78	10.74	10.70	0.39	0.67	1.25	0.85	1.39
BG-51	13.05	11.57	1.48	12.31	12.29	12.27	0.29	0.88	1.46	0.89	1.46
BG-52	10.67	0.00	10.67	5.34	0.00	0.00	2.54	0.00	0.00	0.00	0.00
BG-53	11.77	11.38	0.39	11.58	11.57	11.57	0.08	0.78	1.43	0.97	1.59
BG-54	15.68	15.23	0.45	15.46	15.45	15.45	0.07	1.40	1.92	0.97	1.60
BG-55	17.19	15.87	1.32	16.53	16.52	16.50	0.20	1.60	2.00	0.92	1.52
BG-56	18.35	14.77	3.58	16.56	16.46	16.37	0.50	1.59	1.86	0.80	1.33
BG-57	17.18	16.55	0.63	16.87	16.86	16.86	0.09	1.66	2.09	0.96	1.59
BG-58	16.48	15.12	1.36	15.80	15.79	15.77	0.21	1.46	1.91	0.92	1.51

Table 4.2.3: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of fruit diameter based indices used to evaluate overall heat tolerance

Genotype	FDns	FDhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	Mean ±SD
BG-01	51	29	7	33	33	33	8	33	29	8	8	272	24.73 ±14.68
BG-02	38	23	11	25	24	24	15	24	23	15	15	237	21.55±7.38
BG-03	36	28	22	28	28	28	24	28	28	24	24	298	27.09±3.73
BG-04	39	40	49	49	40	40	40	40	40	40	40	457	41.55±3.70
BG-05	6	6	18	6	6	6	13	6	6	13	13	99	9.00±4.38
BG-06	58	39	30	43	39	39	37	39	39	37	37	437	39.73±6.81
BG-07	43	25	10	27	27	27	16	27	25	16	16	259	23.55±8.86
BG-08	19	17	31	15	15	16	28	15	17	28	28	229	20.82±6.45
BG-09	40	40	47	50	40	40	40	40	40	40	40	457	41.55±3.50
BG-10	11	11	25	11	11	11	19	11	11	19	19	159	14.45±5.07
BG-11	15	40	55	42	40	40	40	40	40	40	40	432	39.27±9.21
BG-12	22	20	34	19	19	19	32	19	20	32	32	268	24.36±6.53
BG-13	33	40	51	47	40	40	40	40	40	40	40	451	41.00±4.56
BG-14	34	40	50	48	40	40	40	40	40	40	40	452	41.09±4.32
BG-15	18	40	54	44	40	40	40	40	40	40	40	436	39.64±8.33
BG-16	42	27	14	30	29	29	20	29	27	20	20	287	26.09±7.44
BG-17	36	26	16	26	26	26	21	26	26	21	21	271	24.64±5.05
BG-18	56	36	26	37	36	36	31	36	36	31	31	392	35.64±7.58
BG-19	45	38	39	38	38	38	39	38	38	39	39	429	39.00±2.05
BG-20	8	40	57	40	40	40	40	40	40	40	40	425	38.64±11.37
BG-21	30	22	13	22	22	22	18	22	22	18	18	229	20.82±4.21
BG-22	50	40	43	55	40	40	40	40	40	40	40	468	42.55±5.13
BG-23	57	40	40	58	40	40	40	40	40	40	40	475	43.18±7.08
BG-24	28	34	36	29	30	30	36	30	34	36	36	359	32.64±3.23
BG-25	54	40	41	57	40	40	40	40	40	40	40	472	42.91±6.27
BG-26	47	40	45	53	40	40	40	40	40	40	40	465	42.27±4.31
BG-27	44	40	46	52	40	40	40	40	40	40	40	462	42.00±3.90
BG-28	48	35	31	36	35	35	34	35	35	34	34	392	35.64±4.30
BG-29	1	40	58	34	40	40	40	40	40	40	40	413	37.55±13.47
BG-30	31	40	52	46	40	40	40	40	40	40	40	449	40.82±5.04

Table 4.2.3: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of fruit diameter based indices used to evaluate overall heat tolerance (cont'd)

Genotype	FDns	FDhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	Mean ±SD
BG-31	14	40	56	41	40	40	40	40	40	40	40	431	39.18±9.62
BG-32	28	30	33	24	25	25	33	25	30	33	33	319	29.00±3.74
BG-33	21	40	53	45	40	40	40	40	40	40	40	439	39.91±7.45
BG-34	55	37	37	39	37	37	38	37	37	38	38	430	39.09±5.32
BG-35	20	14	8	14	14	14	7	14	14	7	7	133	12.09 ± 4.23
BG-36	24	15	1	16	16	15	1	16	15	1	1	121	11.00 ± 8.32
BG-37	8	7	17	7	7	7	11	7	7	11	11	100	9.09 ± 3.18
BG-38	53	33	9	35	34	34	10	34	33	10	10	295	26.82 ± 14.66
BG-39	25	16	2	17	17	17	2	17	16	2	2	133	12.09 ± 8.37
BG-40	3	4	35	2	2	2	26	2	4	26	26	132	12.00±13.14
BG-41	16	13	29	13	13	13	27	13	13	27	27	204	18.55±7.17
BG-42	10	3	6	5	5	5	6	5	3	6	6	60	5.45±1.86
BG-43	26	21	24	20	20	20	25	20	21	25	25	247	22.45±2.50
BG-44	46	31	15	32	32	32	22	32	31	22	22	317	28.82±8.22
BG-45	17	12	12	12	12	12	9	12	12	9	9	128	11.64±2.25
BG-46	12	10	20	10	10	10	17	10	10	17	17	143	13.00±3.90
BG-47	27	24	27	23	23	23	29	23	24	29	29	281	25.55±2.66
BG-48	40	40	47	50	40	40	40	40	40	40	40	457	41.55±3.50
BG-49	49	40	44	54	40	40	40	40	40	40	40	467	42.45±4.76
BG-50	34	32	27	31	31	31	30	31	32	30	30	339	30.82±1.72
BG-51	23	18	23	18	18	18	23	18	18	23	23	223	20.27±2.61
BG-52	52	40	42	56	40	40	40	40	40	40	40	470	42.73±5.68
BG-53	32	19	3	21	21	21	4	21	19	4	4	169	15.36±9.85
BG-54	13	5	4	9	9	9	3	9	5	3	3	72	6.55±3.39
BG-55	4	2	19	4	3	3	12	3	2	12	12	76	6.91±5.79
BG-56	2	9	38	3	4	4	35	4	9	35	35	178	16.18±15.69
BG-57	5	1	5	1	1	1	5	1	1	5	5	31	2.82±2.09
BG-58	7	8	21	7	8	8	14	8	8	14	14	117	10.64±4.50

Note: FDns=Fruit Diameter under non-stress, FDhs=fruit diameter under heat stress conditions

The combination of high yield (Yp=5, Ys=1) and high STI, GMP, and MP ranks confirms its inherent genetic resilience. Similar multi trait stress tolerance indices ranking approaches have been advocated in stress tolerance classification by Fernandez (1992) and Farshadfar *et al.* (2013).

A set of genotypes with medium-ranged mean ranks ($15 < \overline{R} \leq 30$) showed partial fruit diameter retention under heat stress. These included BG-01, BG-02, BG-07, BG-08, BG-10, BG-12, BG-16, BG-17, BG-21, BG-24, BG-28, BG-32, BG-38, BG-41, BG-43, BG-44, BG-47, BG-50, and BG-51. These genotypes can serve as secondary donors in heat-tolerance breeding, especially where yield stability was preferred over maximum productivity. Genotypes with very high mean ranks ($\overline{R} \geq 35$) and high SDR demonstrated severe heat sensitivity and inconsistent performance. These include BG-04, BG-06, BG-09, BG-11, BG-13, BG-14, BG-15, BG-18, BG-19, BG-20, BG-22, BG-23, BG-25, BG-26, BG-27, BG-29, BG-30, BG-31, BG-33, BG-34, BG-48, BG-49, BG-52, and BG-56. These genotypes had high SSI, low YSI and were consistently ranked poorly in Yp and Ys, indicating substantial reduction or elimination of yield under heat. These genotypes were not suitable for production at high temperature stress and must be avoided in breeding for heat tolerance.

4.2.2 Number of fruits per plant-based heat stress tolerance indices

The number of fruits per plant (NFP) is also important yield-contributing components in bottle gourd and highly sensitive to heat stress during flowering and fruit set. There was substantial genotypic variation for number of fruits per plant observed among the fifty-eight genotypes evaluated under optimum (NFPns) and heat stress (NFPhs) conditions, indicating the presence of exploitable variability for heat tolerance.

4.2.2.1 Stress tolerance indices

The number of fruits per plant ranged widely from 5.67 (BG-15) to 18.33 fruits per plant (BG-43) under optimum sowing conditions, confirming considerable genetic diversity. Besides this, during heat stress the magnitude of reduction differed substantially, reflecting differential heat sensitivity. Among the studied genotypes, such as BG-18 (9.46), BG-35 (11.03), BG-02 (10.78), BG-57 (10.98), and BG-58 (12.67), possessed higher number of fruits per plant (Table 4.2.4). These genotypes demonstrated strong heat tolerance and sustained reproduction ability, i.e., fruit number under elevated high temperatures. Besides

this, nineteen genotypes (e.g., BG-04, BG-09, BG-11, BG-13, BG-14, BG-15, BG-20, BG-22, etc.) produced no fruits under heat stress, indicating complete reproductive failure and higher susceptibility level. These genotypes exhibited 100% reduction (RC) in fruit number and extremely low or zero stress tolerance indices.

The low tolerance index (TOL) values exhibited in genotypes BG-18 (0.21), BG-16 (0.34), BG-08 (0.66), BG-28 (0.66), and BG-10 (0.67), indicating superior yield stability under heat stress with minimal reduction in number of fruits per plant. These genotypes were therefore promising for cultivation under heat-stressed environments. In contrast, genotypes BG-24 (5.67), BG-43 (5.33), BG-38 (4.67), and BG-40 (4.00) recorded high TOL values, suggesting higher yield potential but poor stability under heat stress conditions. The tolerance indices MP, GMP, and HM consistently identified BG-18, BG-35, BG-57, BG-58, BG-02, BG-07, and BG-36 as superior genotypes, reflecting their broad adaptability across environments. Similarly, higher and desirable stress tolerance index (STI) values were recorded in BG-18, BG-16, BG-35, BG-02, and BG-57, indicating better yield stability under heat stress compared with high-yielding but unstable genotypes such as BG-43. Yield Index (YI) and Yield Stability Index (YSI) further confirmed the heat resilience of BG-18, BG-35, BG-02, BG-57, BG-58, and BG-07, as these genotypes consistently maintained high and stable yields under stress.

Based on the combined performance of stress indices and stability of number of fruits per plant under both optimum and heat-stress conditions, the genotypes were categorized into distinct groups. Genotypes BG-18, BG-16, BG-35, BG-02, BG-07, BG-08, BG-28, BG-36, BG-57, and BG-58 were classified as highly heat-tolerant, showing minimal fruit reduction and strong performance across all indices. Genotypes BG-03, BG-05, BG-06, BG-10, BG-12, BG-17, and BG-37 showed moderate tolerance, with intermediate reductions and medium index values. In contrast, genotypes BG-04, BG-09, BG-11, BG-13, BG-14, BG-20, and BG-22 were heat-susceptible, producing little to no fruit under stress and exhibiting poor performance across all stress indices.

4.2.2.2 Ranking of number of fruits per plant-based indices

The overall ranks of the number of fruits per plant provided a combined assessment of heat tolerance among the 58 studied bottle gourd genotypes. The rank mean ($\bar{R}$) and standard deviation of ranks (SDR) revealed remarkable variation, indicated differential stability and adaptability across heat environments.

Table 4.2.4: Number of fruits per plant (NFP), NFPns and NFPhs under optimum and heat stress conditions and stress tolerance indices of different bottle gourd genotypes

Genotype	NFPns	NFPhs	RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-01	11.97	9.61	19.72	2.36	10.79	10.73	10.66	0.43	1.23	1.83	0.80	1.47
BG-02	12.10	10.78	10.91	1.32	11.44	11.42	11.40	0.24	1.40	2.05	0.89	1.64
BG-03	12.57	6.33	49.64	6.24	9.45	8.92	8.42	1.09	0.85	1.20	0.50	0.93
BG-04	11.87	0.00	100.00	11.87	5.94	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-05	8.10	6.00	25.93	2.10	7.05	6.97	6.89	0.57	0.52	1.14	0.74	1.36
BG-06	8.57	7.39	13.77	1.18	7.98	7.96	7.94	0.30	0.68	1.40	0.86	1.58
BG-07	9.93	8.89	10.47	1.04	9.41	9.40	9.38	0.23	0.94	1.69	0.90	1.64
BG-08	9.33	8.67	7.07	0.66	9.00	8.99	8.99	0.16	0.87	1.65	0.93	1.71
BG-09	8.33	0.00	100.00	8.33	4.17	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-10	6.00	5.33	11.17	0.67	5.67	5.66	5.65	0.25	0.34	1.01	0.89	1.63
BG-11	6.00	0.00	100.00	6.00	3.00	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-12	6.33	4.33	31.60	2.00	5.33	5.24	5.14	0.69	0.29	0.82	0.68	1.26
BG-13	10.33	0.00	100.00	10.33	5.17	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-14	6.33	0.00	100.00	6.33	3.17	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-15	5.67	0.00	100.00	5.67	2.84	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-16	8.67	8.33	3.92	0.34	8.50	8.50	8.50	0.09	0.77	1.58	0.96	1.77
BG-17	10.67	8.33	21.93	2.34	9.50	9.43	9.36	0.48	0.95	1.58	0.78	1.43
BG-18	9.67	9.46	2.17	0.21	9.57	9.56	9.56	0.05	0.98	1.80	0.98	1.80
BG-19	7.33	4.67	36.29	2.66	6.00	5.85	5.71	0.80	0.37	0.89	0.64	1.17
BG-20	9.00	0.00	100.00	9.00	4.50	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-21	8.67	7.67	11.53	1.00	8.17	8.15	8.14	0.25	0.71	1.46	0.88	1.63
BG-22	9.67	0.00	100.00	9.67	4.84	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-23	7.00	0.00	100.00	7.00	3.50	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-24	11.00	5.33	51.55	5.67	8.17	7.66	7.18	1.13	0.63	1.01	0.48	0.89
BG-25	7.67	0.00	100.00	7.67	3.84	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-26	10.00	0.00	100.00	10.00	5.00	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-27	7.33	0.00	100.00	7.33	3.67	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-28	9.33	8.67	7.07	0.66	9.00	8.99	8.99	0.16	0.87	1.65	0.93	1.71
BG-29	9.33	0.00	100.00	9.33	4.67	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-30	8.33	0.00	100.00	8.33	4.17	0.00	0.00	2.19	0.00	0.00	0.00	0.00

Here, NFPns and NFPhs means number of fruits per plant under non-stress heat stress conditions

Table 4.2.4: Number of fruits per plant (NFP), NFPns and NFPhs under optimum and heat stress conditions and stress tolerance indices of different bottle gourd genotypes (Cont'd)

Genotype	NFPns	NFPhs	RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-31	8.00	0.00	100.00	8.00	4.00	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-32	7.33	4.00	45.43	3.33	5.67	5.41	5.18	1.00	0.31	0.76	0.55	1.00
BG-33	10.00	0.00	100.00	10.00	5.00	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-34	6.67	3.67	44.98	3.00	5.17	4.95	4.73	0.99	0.26	0.70	0.55	1.01
BG-35	11.67	11.03	5.48	0.64	11.35	11.35	11.34	0.12	1.38	2.10	0.95	1.74
BG-36	10.00	9.28	7.20	0.72	9.64	9.63	9.63	0.16	0.99	1.76	0.93	1.70
BG-37	11.67	9.67	17.14	2.00	10.67	10.62	10.58	0.38	1.21	1.84	0.83	1.52
BG-38	11.00	6.33	42.45	4.67	8.67	8.34	8.04	0.93	0.74	1.20	0.58	1.06
BG-39	11.67	10.00	14.31	1.67	10.84	10.80	10.77	0.31	1.25	1.90	0.86	1.57
BG-40	10.33	6.33	38.72	4.00	8.33	8.09	7.85	0.85	0.70	1.20	0.61	1.13
BG-41	9.33	5.00	46.41	4.33	7.17	6.83	6.51	1.02	0.50	0.95	0.54	0.98
BG-42	9.33	8.33	10.72	1.00	8.83	8.82	8.80	0.24	0.83	1.58	0.89	1.64
BG-43	18.33	13.00	29.08	5.33	15.67	15.44	15.21	0.64	2.55	2.47	0.71	1.30
BG-44	8.33	4.33	48.02	4.00	6.33	6.01	5.70	1.05	0.39	0.82	0.52	0.95
BG-45	11.00	9.17	16.64	1.83	10.09	10.04	10.00	0.37	1.08	1.74	0.83	1.53
BG-46	7.67	5.67	26.08	2.00	6.67	6.59	6.52	0.57	0.47	1.08	0.74	1.36
BG-47	11.00	6.33	42.45	4.67	8.67	8.34	8.04	0.93	0.74	1.20	0.58	1.06
BG-48	10.33	0.00	100.00	10.33	5.17	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-49	9.00	0.00	100.00	9.00	4.50	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-50	9.33	4.67	49.95	4.66	7.00	6.60	6.22	1.10	0.47	0.89	0.50	0.92
BG-51	9.67	5.33	44.88	4.34	7.50	7.18	6.87	0.98	0.55	1.01	0.55	1.01
BG-52	8.33	0.00	100.00	8.33	4.17	0.00	0.00	2.19	0.00	0.00	0.00	0.00
BG-53	13.00	11.67	10.23	1.33	12.34	12.32	12.30	0.22	1.62	2.22	0.90	1.65
BG-54	15.00	11.67	22.20	3.33	13.34	13.23	13.13	0.49	1.87	2.22	0.78	1.43
BG-55	9.67	8.33	13.86	1.34	9.00	8.98	8.95	0.30	0.86	1.58	0.86	1.58
BG-56	9.00	8.00	11.11	1.00	8.50	8.49	8.47	0.24	0.77	1.52	0.89	1.63
BG-57	12.33	10.98	10.95	1.35	11.66	11.64	11.62	0.24	1.45	2.09	0.89	1.64
BG-58	14.67	12.67	13.63	2.00	13.67	13.63	13.60	0.30	1.99	2.41	0.86	1.59

Table 4.2.5: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) for number of fruits per plant based on stress tolerance indices used to evaluate overall heat tolerance

Genotype	NFPns	NFPhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	Mean ±SDR
BG-01	8	10	25	9	9	9	21	9	10	21	21	152	13.82±6.60
BG-02	7	7	13	6	6	6	10	6	7	10	10	88	8.00±2.37
BG-03	5	24	41	15	19	22	37	19	24	37	37	280	25.45±11.26
BG-04	9	40	58	36	40	40	40	40	40	40	40	423	38.45±11.29
BG-05	45	28	23	31	30	29	24	30	28	24	24	316	28.73±6.12
BG-06	40	23	12	28	27	26	16	27	23	16	16	254	23.09±7.89
BG-07	24	14	11	16	15	14	8	15	14	8	8	147	13.36±4.67
BG-08	29	15	4	17	16	16	4	16	15	4	4	140	12.73±7.94
BG-09	41	40	47	49	40	40	40	40	40	40	40	457	41.55±3.24
BG-10	56	30	6	37	36	36	13	36	30	13	13	306	27.82±14.91
BG-11	56	40	40	57	40	40	40	40	40	40	40	473	43.00±6.68
BG-12	54	36	19	39	38	38	27	38	36	27	27	379	34.45±9.22
BG-13	18	40	56	41	40	40	40	40	40	40	40	435	39.55±8.59
BG-14	54	40	42	56	40	40	40	40	40	40	40	472	42.91±6.02
BG-15	58	40	38	58	40	40	40	40	40	40	40	474	43.09±7.40
BG-16	38	17	2	23	21	20	2	21	17	2	2	165	15.00±11.72
BG-17	17	17	24	14	14	15	22	14	17	22	22	198	18.00±3.79
BG-18	25	11	1	13	13	13	1	13	11	1	1	103	9.36±7.63
BG-19	49	34	26	35	35	34	28	35	34	28	28	366	33.27±6.28
BG-20	35	40	50	47	40	40	40	40	40	40	40	452	41.09±4.01
BG-21	38	22	8	26	25	23	14	25	22	14	14	231	21.00±8.17
BG-22	25	40	53	45	40	40	40	40	40	40	40	443	40.27±6.47
BG-23	52	40	43	55	40	40	40	40	40	40	40	470	42.73±5.44
BG-24	13	30	38	27	28	28	39	28	30	39	39	339	30.82±7.81
BG-25	47	40	45	53	40	40	40	40	40	40	40	465	42.27±4.31
BG-26	21	40	54	43	40	40	40	40	40	40	40	438	39.82±7.52
BG-27	49	40	44	54	40	40	40	40	40	40	40	467	42.45±4.76
BG-28	29	15	4	17	16	16	4	16	15	4	4	140	12.73±7.94
BG-29	29	40	52	46	40	40	40	40	40	40	40	447	40.64±5.45
BG-30	41	40	47	49	40	40	40	40	40	40	40	457	41.55±3.24

Table 4.2.5: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) for number of fruits per plant based on stress tolerance indices used to evaluate overall heat tolerance (Cont'd)

Genotype	NFPns	NFPhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	Mean ±SDR
BG-31	46	40	46	52	40	40	40	40	40	40	40	464	42.18±4.05
BG-32	49	38	28	37	37	37	34	37	38	34	34	403	36.64±5.03
BG-33	21	40	54	43	40	40	40	40	40	40	40	438	39.82±7.52
BG-34	53	39	27	40	39	39	33	39	39	33	33	414	37.64±6.55
BG-35	10	5	3	7	7	7	3	7	5	3	3	60	5.45±2.34
BG-36	21	12	7	12	12	12	6	12	12	6	6	118	10.73±4.43
BG-37	10	9	19	10	10	10	20	10	9	20	20	147	13.36±5.08
BG-38	13	24	35	21	23	24	30	23	24	30	30	277	25.18±5.88
BG-39	10	8	17	8	8	8	18	8	8	18	18	129	11.73±4.82
BG-40	18	24	30	25	26	27	29	26	24	29	29	287	26.09±3.42
BG-41	29	33	32	30	31	32	35	31	33	35	35	356	32.36±2.06
BG-42	29	17	8	20	20	19	9	20	17	9	9	177	16.09±6.63
BG-43	1	1	37	1	1	1	26	1	1	26	26	122	11.09±14.32
BG-44	41	36	30	34	34	35	36	34	36	36	36	388	35.27±2.61
BG-45	13	13	18	11	11	11	19	11	13	19	19	158	14.36±3.59
BG-46	47	29	19	33	33	31	25	33	29	25	25	329	29.91±7.18
BG-47	13	24	35	21	23	24	30	23	24	30	30	277	25.18±5.88
BG-48	18	40	56	41	40	40	40	40	40	40	40	435	39.55±8.59
BG-49	35	40	50	47	40	40	40	40	40	40	40	452	41.09±4.01
BG-50	29	34	34	32	32	33	38	32	34	38	38	374	34.00±2.93
BG-51	25	30	33	29	29	30	32	29	30	32	32	331	30.09±2.21
BG-52	41	40	47	49	40	40	40	40	40	40	40	457	41.55±3.24
BG-53	4	3	14	4	4	4	7	4	3	7	7	61	5.55±3.21
BG-54	2	3	28	3	3	3	23	3	3	23	23	117	10.64±10.88
BG-55	25	17	15	17	18	18	17	18	17	17	17	196	17.82±2.52
BG-56	35	21	8	23	22	21	12	22	21	12	12	209	19.00±7.55
BG-57	6	6	16	5	5	5	11	5	6	11	11	87	7.91±3.73
BG-58	3	2	19	2	2	2	15	2	2	15	15	79	7.18±7.08

Genotypes such as BG-35 (5.45), BG-53 (5.55), BG-58 (7.18), BG-57 (7.91), BG-02 (8.00), and BG-18 (9.36) possessed higher ranks in tolerance indices, TOL, MP, GMP, HM, SSI, STI and YSI. Their lower SDR values indicated the consistency and high reliability, suggesting stable performance under heat stress. Such type of stability was desirable in heat stress-breeding programs, as reported by Fernandez (1992), who emphasized the value of stable, high-performing genotypes for stress environments. Besides this, the genotypes such as BG-11, BG-15, BG-09, and BG-20 showed higher rankings ($\overline{R} > 40$), indicating poor performance in all tolerance indices and expressed their extreme sensitivity to heat stress. Higher SDR values in genotypes such as BG-10 and BG-43 suggested inconsistent performance across indices Although genotypes BG-43 ranked first in optimum conditions traits due to its superior fruit number, but it exhibited poor ranks in stress indices, meaning that high yield potential alone did not ensured heat tolerance, but need to consistent performance under both environments. Such types of ranking were elaborated and described by Naghavi *et al.* (2013) in corn. Thus, genotypes BG-35, BG-53, BG-58, and BG-18 were identified as superior genotypes, represent strong candidates for heat-tolerant breeding for cultivation in heat stress vulnerable region.

4.2.3 Fruit weight-based stress tolerance indices

4.2.3.1 Stress tolerance indices

Considerable variation was observed among the 58 bottle gourd genotypes for fruit weight under both optimum (FWns) and heat-stress (FWhs) conditions, indicating substantial genetic diversity in the ability to maintain fruit mass under high-temperature field environments. Fruit weight ranged from 1.23 to 2.62 kg under optimum sowing, but declined to 1.03–1.94 kg under heat stress (Table 4.2.1). While several genotypes showed little or no reduction in fruit weight, nineteen genotypes failed to produce fruits under stress (FWhs = 0.00), reflecting complete susceptibility to heat stress.

Genotypes BG-45 and BG-39 showed the lowest fruit weight reduction (RC = 2.0% and 2.7%), coupled with very low SSI (0.04 and 0.06) and high YSI (0.98 and 0.97), indicating exceptional stability and minimal heat stress impact. Genotypes BG-53, BG-28, BG-35, BG-36, BG-37, BG-08, BG-02, BG-21, and BG-57 exhibited moderate fruit weight reduction with favorable MP, GMP, HM, and low SSI values, suggesting balanced productivity and good heat tolerance.

In contrast, nineteen genotypes (BG-04, BG-09, BG-11, BG-13, BG-14, BG-15, BG-20, BG-22, BG-23, BG-25, BG-26, BG-27, BG-29, BG-30, BG-31, BG-33, BG-48, BG-49, and BG-52) recorded 100% fruit weight reduction (RC = 100%), along with the highest SSI and zero GMP, HM, STI, YI, and YSI values, confirming extreme heat susceptibility. Another group of genotypes (BG-12, BG-16, BG-24, BG-32, BG-34, BG-38, BG-41, BG-44, BG-50, BG-51, and BG-56) showed moderate tolerance (RC = 10–35%), indicating partial but unstable adaptation to heat stress. The genotypes, BG-45, BG-39, BG-28, BG-53, BG-35, and BG-36 emerged as the most promising genotypes, combining low fruit weight reduction, low stress susceptibility, and high stability indices, and were therefore suitable candidates for cultivation and for use as parents in breeding programs aimed at improving fruit weight stability under heat-stress conditions.

4.2.3.2 Ranking of stress tolerance indices on fruit weight

The rank analysis of fruit weight-based indices revealed substantial differences in overall heat tolerance among the evaluated bottle gourd genotypes (4.2.7). Among these, BG-45 showed the best combined ranking (4.64), confirming its superior stability of fruit weight under heat stress followed by BG-28 (5.73) and BG-39 (9.64), which also performed good, indicating the strong tolerance and yield stability across both at optimum and heat stress environments. Superior performance of stress tolerance indices TOL, SSI, STI, YSI, and YI indices the genotypes such as BG-45, BG-28, BG-39, BG-02, BG-21, BG-36 and BG-38 exhibited the lowest mean rank values, reflecting consistently superior performance. Beside this, genotypes such as BG-41, BG-46, BG-44, BG-16 and BG-24, showed intermediate rank values, suggesting partial or inconsistent tolerance. Conversely, nineteen genotypes including BG-20, BG-04, BG-09, BG-11, BG-22, BG-25, BG-33, BG-48 and BG-58were recorded very high rank means (Mean R > 36), marked as poor performance and severe susceptibility under heat stress. The combined ranking results identified that genotypes BG-45, BG-28, BG-39, BG-02, and BG-36 were the most promising heat-tolerant genotypes for maintaining fruit weight in high-temperature conditions.

Table 4.2.6: Fruit weight (FW), FWns and FWhs under optimum and heat stress conditions and stress tolerance indices of different bottle gourd genotypes

Genotype	FWns	FWhs	RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-01	1.93	1.59	17.62	0.34	1.76	1.75	1.74	0.38	0.83	1.56	0.82	1.55
BG-02	2.16	1.86	13.89	0.30	2.01	2.00	2.00	0.30	1.09	1.82	0.86	1.62
BG-03	1.73	1.18	31.79	0.55	1.46	1.43	1.40	0.68	0.55	1.16	0.68	1.29
BG-04	1.94	0.00	100.00	1.94	0.97	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-05	1.73	1.40	19.08	0.33	1.57	1.56	1.55	0.41	0.66	1.37	0.81	1.53
BG-06	1.23	1.03	16.26	0.20	1.13	1.13	1.12	0.35	0.34	1.01	0.84	1.58
BG-07	1.92	1.48	22.92	0.44	1.70	1.69	1.67	0.49	0.77	1.45	0.77	1.45
BG-08	1.76	1.59	9.66	0.17	1.68	1.67	1.67	0.21	0.76	1.56	0.90	1.70
BG-09	1.78	0.00	100.00	1.78	0.89	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-10	2.16	1.77	18.06	0.39	1.97	1.96	1.95	0.38	1.03	1.74	0.82	1.55
BG-11	2.00	0.00	100.00	2.00	1.00	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-12	2.33	1.71	26.61	0.62	2.02	2.00	1.97	0.57	1.08	1.68	0.73	1.38
BG-13	2.34	0.00	100.00	2.34	1.17	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-14	2.20	0.00	100.00	2.20	1.10	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-15	2.24	0.00	100.00	2.24	1.12	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-16	2.17	1.63	24.88	0.54	1.90	1.88	1.86	0.53	0.96	1.60	0.75	1.42
BG-17	1.64	1.21	26.22	0.43	1.43	1.41	1.39	0.56	0.54	1.19	0.74	1.39
BG-18	1.57	1.35	14.01	0.22	1.46	1.46	1.45	0.30	0.57	1.32	0.86	1.62
BG-19	1.69	1.43	15.38	0.26	1.56	1.55	1.55	0.33	0.65	1.40	0.85	1.60
BG-20	1.39	0.00	100.00	1.39	0.70	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-21	2.21	1.85	16.29	0.36	2.03	2.02	2.01	0.35	1.11	1.81	0.84	1.58
BG-22	1.88	0.00	100.00	1.88	0.94	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-23	2.02	0.00	100.00	2.02	1.01	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-24	2.29	1.59	30.57	0.70	1.94	1.91	1.88	0.65	0.99	1.56	0.69	1.31
BG-25	1.46	0.00	100.00	1.46	0.73	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-26	2.52	0.00	100.00	2.52	1.26	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-27	2.09	0.00	100.00	2.09	1.05	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-28	2.18	1.94	11.01	0.24	2.06	2.06	2.05	0.23	1.14	1.90	0.89	1.68

Here, RC-Relative Change, TOL-Tolerance index, MP-Mean productivity, GMP-Geometric mean production, HM-Harmonic mean, SSI-Stress susceptibility index, STI-Stress tolerance Index, YI-Yield index, YSI-Yield stability index, RSI-Relative stress index.

Table 4.2.6: Fruit weight (FW), FWns and FWhs under optimum and heat stress conditions and stress tolerance indices of different bottle gourd genotypes (Cont'd)

Genotype	FWns	FWhs	RC	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-29	2.23	0.00	100.00	2.23	1.12	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-30	2.22	0.00	100.00	2.22	1.11	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-31	2.04	0.00	100.00	2.04	1.02	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-32	2.05	1.59	22.44	0.46	1.82	1.81	1.79	0.48	0.88	1.56	0.78	1.46
BG-33	1.43	0.00	100.00	1.43	0.72	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-34	1.99	1.41	29.15	0.58	1.70	1.68	1.65	0.62	0.76	1.38	0.71	1.34
BG-35	1.36	1.22	10.29	0.14	1.29	1.29	1.29	0.22	0.45	1.20	0.90	1.69
BG-36	1.94	1.72	11.34	0.22	1.83	1.83	1.82	0.24	0.90	1.69	0.89	1.67
BG-37	1.83	1.65	9.84	0.18	1.74	1.74	1.74	0.21	0.82	1.62	0.90	1.70
BG-38	2.06	1.73	16.02	0.33	1.90	1.89	1.88	0.34	0.96	1.70	0.84	1.58
BG-39	1.84	1.79	2.72	0.05	1.82	1.81	1.81	0.06	0.89	1.76	0.97	1.83
BG-40	2.10	1.37	34.76	0.73	1.74	1.70	1.66	0.74	0.78	1.34	0.65	1.23
BG-41	2.01	1.53	23.88	0.48	1.77	1.75	1.74	0.51	0.83	1.50	0.76	1.44
BG-42	1.71	1.60	6.43	0.11	1.66	1.65	1.65	0.14	0.74	1.57	0.94	1.76
BG-43	1.42	1.21	14.79	0.21	1.32	1.31	1.31	0.31	0.47	1.19	0.85	1.61
BG-44	2.18	1.55	28.90	0.63	1.87	1.84	1.81	0.62	0.91	1.52	0.71	1.34
BG-45	2.00	1.96	2.00	0.04	1.98	1.98	1.98	0.04	1.06	1.92	0.98	1.85
BG-46	1.87	1.62	13.37	0.25	1.75	1.74	1.74	0.28	0.82	1.59	0.87	1.63
BG-47	1.67	1.16	30.54	0.51	1.42	1.39	1.37	0.65	0.52	1.14	0.69	1.31
BG-48	2.62	0.00	100.00	2.62	1.31	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-49	2.20	0.00	100.00	2.20	1.10	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-50	1.84	1.32	28.26	0.52	1.58	1.56	1.54	0.60	0.66	1.29	0.72	1.35
BG-51	2.37	1.57	33.76	0.80	1.97	1.93	1.89	0.72	1.01	1.54	0.66	1.25
BG-52	2.02	0.00	100.00	2.02	1.01	0.00	0.00	2.13	0.00	0.00	0.00	0.00
BG-53	1.41	1.33	5.67	0.08	1.37	1.37	1.37	0.12	0.51	1.30	0.94	1.78
BG-54	1.43	1.24	13.29	0.19	1.34	1.33	1.33	0.28	0.48	1.22	0.87	1.64
BG-55	1.67	1.48	11.38	0.19	1.58	1.57	1.57	0.24	0.67	1.45	0.89	1.67
BG-56	1.93	1.68	12.95	0.25	1.81	1.80	1.80	0.28	0.88	1.65	0.87	1.64
BG-57	1.83	1.66	9.29	0.17	1.75	1.74	1.74	0.20	0.82	1.63	0.91	1.71
BG-58	1.65	1.12	32.12	0.53	1.39	1.36	1.33	0.68	0.50	1.10	0.68	1.28

Table 4.2.7: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of fruit weight-based indices used to evaluate overall heat tolerance

Genotype	FWns	FWhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	Mean R±SDR
BG-01	31	16	22	17	17	16	22	17	16	22	22	218	19.82±4.60
BG-02	16	3	19	4	3	3	15	3	3	15	15	99	9.00±6.80
BG-03	42	36	33	31	31	31	36	31	36	36	36	379	34.45±3.45
BG-04	29	40	45	53	40	40	40	40	40	40	40	447	40.64±5.57
BG-05	42	27	20	28	28	28	24	28	27	24	24	300	27.27±5.52
BG-06	58	39	11	42	39	39	20	39	39	20	20	366	33.27±13.70
BG-07	33	23	26	22	22	21	26	22	23	26	26	270	24.55±3.42
BG-08	41	16	6	24	24	22	6	24	16	6	6	191	17.36±11.10
BG-09	40	40	43	55	40	40	40	40	40	40	40	458	41.64±4.52
BG-10	16	6	24	7	6	6	23	6	6	23	23	146	13.27±8.43
BG-11	26	40	46	52	40	40	40	40	40	40	40	444	40.36±6.12
BG-12	5	9	35	3	4	5	30	4	9	30	30	164	14.91±13.16
BG-13	4	40	56	41	40	40	40	40	40	40	40	421	38.27±12.33
BG-14	11	40	51	46	40	40	40	40	40	40	40	428	38.91±9.92
BG-15	7	40	55	43	40	40	40	40	40	40	40	425	38.64±11.41
BG-16	15	13	32	9	10	10	28	10	13	28	28	196	17.82±9.10
BG-17	49	34	25	32	32	32	29	32	34	29	29	357	32.45±6.09
BG-18	50	29	13	30	30	30	16	30	29	16	16	289	26.27±10.61
BG-19	45	25	18	29	29	27	18	29	25	18	18	281	25.55±8.03
BG-20	56	40	40	58	40	40	40	40	40	40	40	474	43.09±6.89
BG-21	10	4	23	2	2	2	21	2	4	21	21	112	10.18±9.27
BG-22	34	40	44	54	40	40	40	40	40	40	40	452	41.09±4.85
BG-23	23	40	47	50	40	40	40	40	40	40	40	440	40.00±6.62
BG-24	6	16	37	8	8	9	35	8	16	35	35	213	19.36±13.19
BG-25	51	40	42	56	40	40	40	40	40	40	40	469	42.64±5.52
BG-26	2	40	57	40	40	40	40	40	40	40	40	419	38.09±13.01
BG-27	19	40	50	48	40	40	40	40	40	40	40	437	39.73±7.77
BG-28	13	2	15	1	1	1	9	1	2	9	9	63	5.73±5.37
BG-29	8	40	54	44	40	40	40	40	40	40	40	426	38.73±11.04
BG-30	9	40	53	45	40	40	40	40	40	40	40	427	38.82±10.68

Table 4.2.7: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of fruit weight-based indices used to evaluate overall heat tolerance (Cont'd)

Genotype	FWns	FWhs	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	SR	Mean R±SDR
BG-31	22	40	49	49	40	40	40	40	40	40	40	440	40.00±6.97
BG-32	21	16	27	13	14	15	25	14	16	25	25	211	19.18±5.44
BG-33	52	40	41	57	40	40	40	40	40	40	40	470	42.73±5.93
BG-34	28	26	34	22	23	25	33	23	26	33	33	306	27.82±4.62
BG-35	57	33	5	39	38	38	8	38	33	8	8	305	27.73±17.44
BG-36	29	8	13	12	12	11	10	12	8	10	10	135	12.27±5.78
BG-37	38	12	8	20	20	20	7	20	12	7	7	171	15.55±9.41
BG-38	20	7	20	10	9	8	19	9	7	19	19	147	13.36±5.85
BG-39	36	5	2	14	13	12	2	13	5	2	2	106	9.64±10.09
BG-40	18	28	38	21	21	23	39	21	28	39	39	315	28.64±8.55
BG-41	25	22	28	16	16	18	27	16	22	27	27	244	22.18±4.94
BG-42	44	15	4	25	25	24	4	25	15	4	4	189	17.18±12.86
BG-43	54	34	12	37	37	37	17	37	34	17	17	333	30.27±12.78
BG-44	13	21	36	11	11	13	32	11	21	32	32	233	21.18±10.08
BG-45	26	1	1	5	5	4	1	5	1	1	1	51	4.64±7.32
BG-46	35	14	16	18	19	19	14	19	14	14	14	196	17.82±6.13
BG-47	46	37	29	33	33	33	34	33	37	34	34	383	34.82±4.29
BG-48	1	40	58	38	40	40	40	40	40	40	40	417	37.91±13.42
BG-49	11	40	51	46	40	40	40	40	40	40	40	428	38.91±9.92
BG-50	36	31	30	26	27	29	31	27	31	31	31	330	30.00±2.76
BG-51	3	20	39	6	7	7	38	7	20	38	38	223	20.27±15.25
BG-52	23	40	47	50	40	40	40	40	40	40	40	440	40.00±6.62
BG-53	55	30	3	35	34	34	3	34	30	3	3	264	24.00±17.94
BG-54	52	32	9	36	36	36	13	36	32	13	13	308	28.00±13.78
BG-55	46	23	9	27	26	26	11	26	23	11	11	239	21.73±10.87
BG-56	31	10	16	15	15	14	12	15	10	12	12	162	14.73±5.78
BG-57	38	11	7	18	18	17	5	18	11	5	5	153	13.91±9.71
BG-58	48	38	31	34	35	35	37	35	38	37	37	405	36.82±4.24

4.2.4 Yield-Based Stress Tolerance Indices

4.2.4.1 Stress tolerance indices

The fifty-eight investigated genotypes demonstrated substantial genetic diversity for several morphological traits grown under both heat stress and optimum conditions. The morphological variation of 58 studied bottle gourd genotypes under both normal and heat stress conditions was displayed in Figure 4.2.1. The cropping season's weather data indicates a maximum mean temperature of 34.62°C, with optimal temperatures of 25-30°C for bottle gourd (Akhond *et al.,* 2025, Kumar and Reddy, 2021), and temperatures nearly 5-7$^{\circ C}$ higher during heat stress conditions (Figure 4.2.2). A high stress intensity indicates greater stress severity, which implies a lower yield under stress conditions, and vice versa (Dodig *et al.,* 2008; Devi *et al.,* 2021). Nineteen out of fifty-eight genotypes wilted or died from heat stress during seedling, vegetative, and pre-flowering stages, resulting in 100% fruit yield loss. The surviving plants reduced the yield of fruit by 7.47 to 69.29%, with an average yield loss of 55.26%.

Fruit yield ranged from 0 to 40.73 (t ha^{-1}) and 21.12 kg to 53.96 (t ha^{-1}) in heat-stressed and non-stressed conditions, with an overall mean of 17.08 (t ha^{-1}) and 37.04 (t ha^{-1}), respectively. Under non-stressed conditions, genotypes BG-48, BG-43, and BG-02 produced the highest fruit yield per plant with 53.96, 51.84, and 51.25 t ha^{-1}, respectively, whereas genotypes BG-02, BG-57, and BG-43 produced the highest yield per plant with 40.73, 38.8, and 38.72 t ha^{-1} under heat-stressed conditions (Table 4.2.1). Aside from the nineteen withered genotypes, BG-50, BG-24, and BG-41 had the significantly highest fruit yield reduction at 69%, 67%, and 61%, respectively. Mashilo *et al.* (2017) determined that drought stress reduced yields by 24 to 75% in bottle gourd. The genotypes BG-45, BG-02, BG-57, and BG-43 provided highest yield in both normal and heat stress conditions. Blum (1988) suggests screening for stress tolerance in genotypes based on strong performance in stressed and optimum environments.

Yield-based stress indices TOL, MP, GMP, HM, SSI, STI, YI, YSI and RSI were estimated for the studied bottle gourd genotypes based on yield under both normal and heat-stressed conditions (Table 4.2.8). The genetic variation among genotypes defined by different heat tolerance indices were depicted (Figures 4.2.1, 4.2.2, and 4.2.3). Nineteen bottle gourd genotypes possessed higher TOL, SSI, YSI and RSI values and were marked as heat-susceptible genotypes because they recorded high yield under normal conditions but zero

yield when the plant died under heat stress conditions, and this genotype is only suitable for normal sown conditions. The lowest value of TOL, SSI, YSI and RSI was exhibited in genotype BG-42, followed by BG-18, BG-35 and BG-39 denoted as tolerant to heat stress. These genotypes performed less under both conditions due to a small yield differential, implying that low values do not always indicate high performance and emphasizing the relevance of yield as a crucial factor. Lamba *et al.,* (2023) also suggested determining heat-tolerant genotypes considering lower TOL, SSPI, YSI, RSI values and grain yield, which supported the current findings. Lower SSI (<1.0) and TOL index indicated higher heat tolerance (Devi *et al.,* 2021; Porch, 2006). Superior genotype selection had also been reported based on lower SSI and TOL for drought tolerance in chickpeas (Yucel and Mart, 2014; Jha *et al.,* 2016) and bottle gourd (Mashilo *et al.,* 2017).

Based on the higher values of MP, GMP, HM, STI, and YI combinations, genotype BG-02 were considered to be the most stable and productive genotype, followed by BG-43, BG-57, BG-01, BG-45, and BG-39, which were identified among all the investigated under both conditions as heat resistant. Superior genotypes with heat tolerance might be chosen by combining higher MP, GMP, HM, YI, and STI values, and vice versa (Jahan *et al.,* 2018). Consequently, these genotypes can be recommended as the most stable and productive under a heat stress as well as normal conditions. Similarly, based on these stress tolerance indicators, heat-tolerant genotypes were identified in wheat (Poudel *et al.,* 2024, Lamba *et al.,* 2023) and chickpeas (Jha *et al.,* 2018) and drought tolerance in bottle gourd (Mashilo *et al.,* 2017). Thus, it was revealed that genotypes with a combination of higher MP, GMP, HM, YI, and STI values and lower TOL and SSI values were effective in identifying high-yielding cum heat-tolerant, which identical to the findings reported by Poudel *et al.,* (2024), Lamba *et al.,* (2023) and Jha *et al.,* (2018).

Table 4.2.8: Fruit yield (t ha^{-1}), Yp and Ys under optimum and heat stress conditions and stress tolerance indices of different bottle gourd genotypes

Genotype	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-01	45.94	33.65	12.29	39.80	39.32	38.85	0.50	1.14	1.98	0.73	1.59
BG-02	51.25	40.73	10.52	45.99	45.69	45.39	0.38	1.53	2.40	0.79	1.73
BG-03	42.33	23.59	18.74	32.96	31.60	30.30	0.82	0.73	1.39	0.56	1.21
BG-04	45.56	0.00	45.56	22.78	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-05	36.66	27.56	9.10	32.11	31.79	31.47	0.46	0.74	1.63	0.75	1.64
BG-06	21.12	11.37	9.75	16.25	15.50	14.78	0.85	0.18	0.67	0.54	1.17
BG-07	37.88	27.53	10.35	32.71	32.29	31.89	0.51	0.77	1.62	0.73	1.58
BG-08	31.53	21.05	10.48	26.29	25.76	25.25	0.62	0.49	1.24	0.67	1.45
BG-09	27.51	0.00	27.51	13.76	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-10	26.54	19.38	7.16	22.96	22.68	22.40	0.50	0.38	1.14	0.73	1.59
BG-11	23.71	0.00	23.71	11.86	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-12	28.40	16.88	11.52	22.64	21.90	21.17	0.75	0.35	1.00	0.59	1.29
BG-13	50.74	0.00	50.74	25.37	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-14	28.80	0.00	28.80	14.40	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-15	27.23	0.00	27.23	13.62	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-16	41.22	28.25	12.97	34.74	34.12	33.52	0.58	0.86	1.67	0.69	1.49
BG-17	35.56	24.67	10.89	30.12	29.62	29.13	0.57	0.64	1.45	0.69	1.51
BG-18	27.90	25.06	2.84	26.48	26.44	26.40	0.19	0.51	1.48	0.90	1.95
BG-19	25.51	12.32	13.19	18.92	17.73	16.62	0.96	0.23	0.73	0.48	1.05
BG-20	23.36	0.00	23.36	11.68	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-21	39.26	28.54	10.72	33.90	33.47	33.05	0.51	0.82	1.68	0.73	1.58
BG-22	35.32	0.00	35.32	17.66	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-23	27.25	0.00	27.25	13.63	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-24	50.91	16.85	34.06	33.88	29.29	25.32	1.24	0.63	0.99	0.33	0.72
BG-25	24.68	0.00	24.68	12.34	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-26	48.12	0.00	48.12	24.06	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-27	29.63	0.00	29.63	14.82	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-28	38.88	32.98	5.90	35.93	35.81	35.69	0.28	0.94	1.94	0.85	1.85
BG-29	38.20	0.00	38.20	19.10	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-30	38.08	0.00	38.08	19.04	0.00	0.00	1.85	0.00	0.00	0.00	0.00

Here, TOL-Tolerance index, MP-Mean productivity, GMP-Geometric mean production, HM-Harmonic mean, SSI-Stress susceptibility index, STI-Stress tolerance Index, YI-Yield index, YSI-Yield stability index, RSI-Relative stress index.

Table 4.2.8: Fruit yield (t ha^{-1}), Yp and Ys under normal and heat stress conditions and stress tolerance indices of different bottle gourd genotypes (Cont'd)

Genotype	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
BG-31	35.18	0.00	35.18	17.59	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-32	29.86	14.26	15.60	22.06	20.64	19.30	0.97	0.31	0.84	0.48	1.04
BG-33	23.54	0.00	23.54	11.77	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-34	26.38	11.30	15.08	18.84	17.27	15.82	1.06	0.22	0.67	0.43	0.93
BG-35	32.45	29.09	3.36	30.77	30.72	30.68	0.19	0.69	1.72	0.90	1.95
BG-36	40.66	33.14	7.52	36.90	36.71	36.52	0.34	0.99	1.95	0.82	1.77
BG-37	45.18	33.74	11.44	39.46	39.04	38.63	0.47	1.12	1.99	0.75	1.62
BG-38	44.23	20.46	23.77	32.35	30.08	27.98	0.99	0.66	1.21	0.46	1.01
BG-39	39.36	34.74	4.62	37.05	36.98	36.91	0.22	1.00	2.05	0.88	1.92
BG-40	41.45	19.61	21.84	30.53	28.51	26.62	0.97	0.60	1.16	0.47	1.03
BG-41	36.73	14.50	22.23	25.62	23.08	20.79	1.12	0.39	0.86	0.39	0.86
BG-42	30.51	28.23	2.28	29.37	29.35	29.33	0.14	0.63	1.66	0.93	2.01
BG-43	51.84	38.72	13.12	45.28	44.80	44.33	0.47	1.47	2.28	0.75	1.63
BG-44	42.61	22.16	20.45	32.39	30.73	29.16	0.89	0.69	1.31	0.52	1.13
BG-45	41.88	36.70	5.18	39.29	39.20	39.12	0.23	1.13	2.16	0.88	1.91
BG-46	28.40	20.50	7.90	24.45	24.13	23.81	0.51	0.43	1.21	0.72	1.57
BG-47	39.82	22.88	16.94	31.35	30.18	29.06	0.79	0.67	1.35	0.57	1.25
BG-48	53.96	0.00	53.96	26.98	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-49	40.97	0.00	40.97	20.49	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-50	40.13	12.32	27.81	26.23	22.24	18.85	1.28	0.36	0.73	0.31	0.67
BG-51	45.52	21.71	23.81	33.62	31.44	29.40	0.97	0.73	1.28	0.48	1.04
BG-52	35.20	0.00	35.20	17.60	0.00	0.00	1.85	0.00	0.00	0.00	0.00
BG-53	36.92	30.33	6.59	33.63	33.46	33.30	0.33	0.82	1.79	0.82	1.79
BG-54	42.36	29.77	12.59	36.07	35.51	34.97	0.55	0.93	1.76	0.70	1.53
BG-55	32.76	27.76	5.00	30.26	30.16	30.05	0.28	0.67	1.64	0.85	1.84
BG-56	35.13	28.00	7.13	31.57	31.36	31.16	0.38	0.72	1.65	0.80	1.73
BG-57	48.62	38.80	9.82	43.71	43.43	43.16	0.37	1.39	2.29	0.80	1.74
BG-58	49.42	24.46	24.96	36.94	34.77	32.72	0.93	0.89	1.44	0.49	1.08
Mean	36.90	16.96	19.94	26.93	20.63	20.05	1.02	0.49	1.00	0.45	0.97
Max	53.96	40.73	53.96	45.99	45.69	45.39	1.85	1.53	2.40	0.93	2.01
Min	21.12	0.00	2.28	11.68	0.00	0.00	0.14	0.00	0.00	0.00	0.00
SE(±)	1.12	1.79	1.73	1.22	2.06	2.03	0.08	0.06	0.11	0.05	0.10
SD	8.56	13.63	13.15	9.29	15.70	15.44	0.64	0.44	0.80	0.34	0.75
CV	0.23	0.80	0.65	0.34	0.75	0.76	0.62	0.89	0.80	0.76	0.76

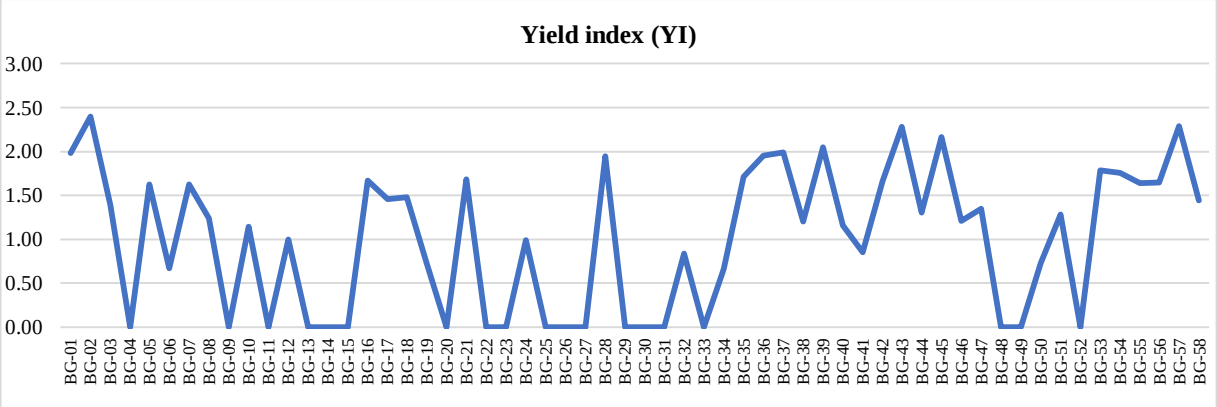


Figure 4.2.1 Mean comparison of yield index (YI) as a function of non stress and heat stress condition in different bottle gourd genotypes

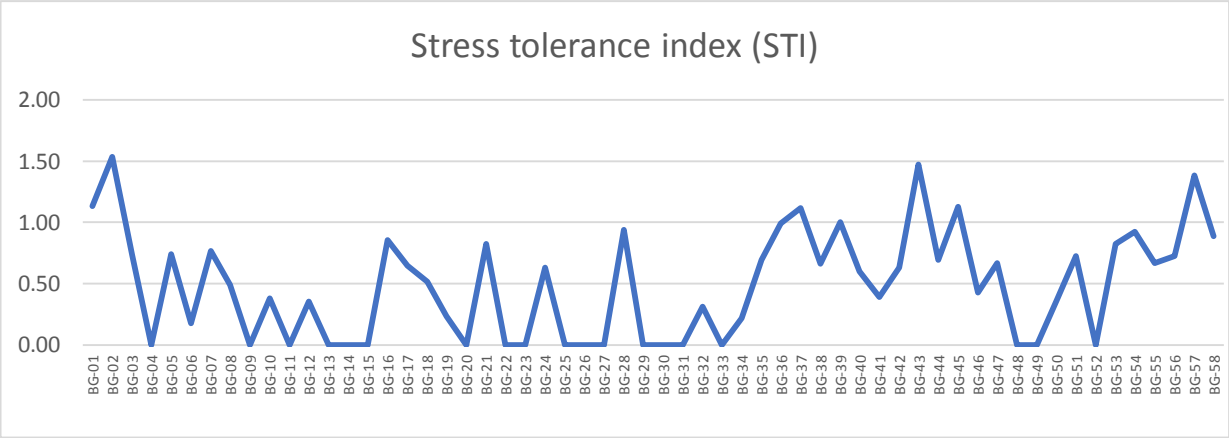


Figure 4.2.2 Mean comparison of stress tolerance index (STI) as a function of non-stress and heat stress condition in different bottle gourd genotypes

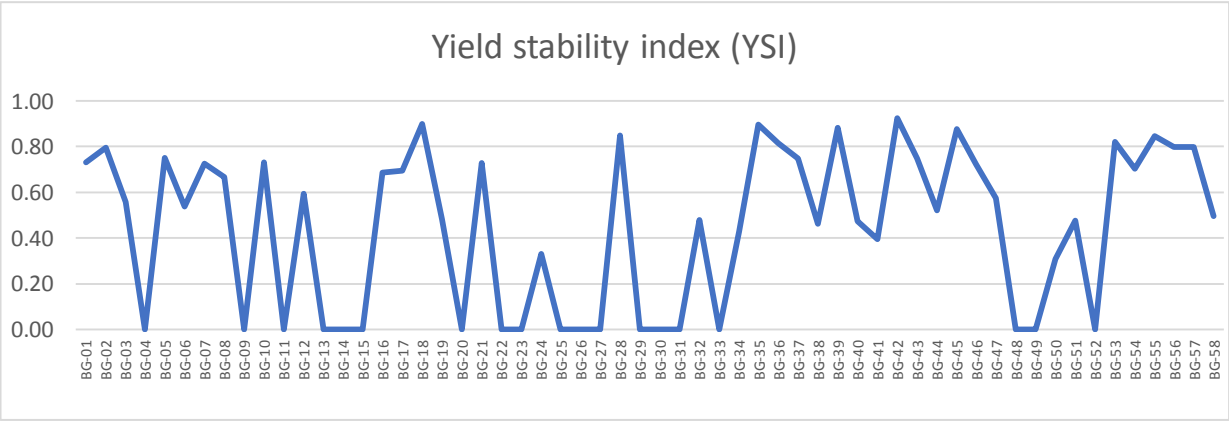


Figure 4.2.3. Mean comparison of yield stability index (YSI) as a function of non-stress and heat stress condition in different bottle gourd genotypes

4.2.4.2 Ranking of bottle gourd genotypes on fruit yield

The estimates of heat tolerance indices were inconsistent and contradictory to identify heat-tolerant cultivars across many criteria resulted in various genotypes were identified as heat tolerant by various metrics. Therefore, the ranking system was used to determine the overall performance of genotypes. In order to identify the most heat-tolerant genotype based on all indicators, the mean rank ($\bar{R}$), SDR, and RS of all heat tolerance indices were estimated. BG-02, BG-45, and BG-57 were identified as the most heat-tolerant genotypes with low RS values based on all indices (Table 4.2.9). Mashilo *et al.* (2017) used ranking system of bottle gourd to identify drought-tolerant genotypes, which aligned with current findings. The genotypes selection through stress tolerance indices ranking system supported by drought tolerance genotypes selection in canola (Khalili *et al.,* 2012), drought screening of corn (Naghavi *et al.,* 2013) and drought tolerance in wheat (Farshadfar *et al.,* 2013).

4.2.4.3 Correlation between fruit yield and stress tolerance indices

The correlation coefficient between fruit yield under optimum (Yp) and heat-stressed conditions (Ys) and heat tolerance indices were estimated to determine a suitable stress-tolerant criterion. The indices that showed a strong relationship with fruit yield in both environments were chosen as the best to use in selecting genotypes with high yield in both conditions (Table 4.2.10).

Fruit yield under optimum cultivated conditions (Yp) was positive, and significant association (0.369) with fruit yield under heat stress conditions (Ys) suggested that they might be utilized to select yielding bottle gourd genotypes. Fruit yield in heat stress condition (Ys) was positive and highly significant association with MP (0.904), GMP (0.983), HM (0.991), STI (0.968), YI (1), YSI (0.952) and RSI (0.953) but highly negative significant association with TOL (-0.796) and SSI (-0.952). Whereas, Yp showed a positive and significant correlation with TOL (0.268), MP (0.732), GMP (0.405), HM (0.396), STI (0.514) and YI (0.369). Under heat stress, fruit yield was negatively correlated with TOL (-0.80) while positively correlated (0.27) under normal conditions so, selection according these indices will therefore yield more fruit under normal conditions but less under heat stress (Lamba *et al.,* 2023). Fruit yield (Yp and Ys) were determined to be positively correlated with MP, GMP, HM, and STI, and negatively associated with TOL and SSI for wheat heat tolerance (Poudel *et al.,* 2024) and in chickpeas heat tolerance

Table 4.2.9: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of yield-based indices used to evaluate overall heat tolerance

Genotype	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	$\bar{R}$± SDR
BG-01	9	7	23	4	4	5	16	4	7	16	16	10.09±6.55
BG-02	3	1	18	1	1	1	12	1	1	12	12	5.73±6.40
BG-03	16	23	31	17	17	19	27	17	23	27	27	22.18±5.27
BG-04	10	40	55	38	40	40	40	40	40	40	40	38.45±10.50
BG-05	32	18	13	21	16	16	13	16	18	13	13	17.18±5.56
BG-06	58	38	14	49	39	39	28	39	38	28	28	36.18±11.68
BG-07	29	19	16	18	15	15	19	15	19	19	19	18.45±3.93
BG-08	40	27	17	31	30	30	24	30	27	24	24	27.64±5.78
BG-09	48	40	44	52	40	40	40	40	40	40	40	42.18±4.14
BG-10	51	31	10	37	33	32	17	33	31	17	17	28.09±11.75
BG-11	55	40	37	56	40	40	40	40	40	40	40	42.55±6.47
BG-12	45	32	22	39	35	33	25	35	32	25	25	31.64±6.95
BG-13	5	40	57	34	40	40	40	40	40	40	40	37.82±12.24
BG-14	44	40	46	51	40	40	40	40	40	40	40	41.91±3.65
BG-15	50	40	42	54	40	40	40	40	40	40	40	42.36±4.88
BG-16	19	14	25	12	12	11	23	12	14	23	23	17.09±5.52
BG-17	33	21	20	27	25	24	22	25	21	22	22	23.82±3.71
BG-18	47	20	2	30	29	28	2	29	20	2	2	19.18±15.31
BG-19	53	36	27	44	37	37	31	37	36	31	31	36.36±7.15
BG-20	57	40	35	58	40	40	40	40	40	40	40	42.73±7.46
BG-21	25	13	19	13	13	13	18	13	13	18	18	16.00±3.95
BG-22	34	40	51	46	40	40	40	40	40	40	40	41.00±4.27
BG-23	49	40	43	53	40	40	40	40	40	40	40	42.27±4.50
BG-24	4	33	48	14	27	29	38	27	33	38	38	29.91±12.19
BG-25	54	40	40	55	40	40	40	40	40	40	40	42.64±5.87
BG-26	8	40	56	36	40	40	40	40	40	40	40	38.18±11.22
BG-27	43	40	47	50	40	40	40	40	40	40	40	41.82±3.49
BG-28	26	9	7	11	9	9	6	9	9	6	6	9.73±5.64
BG-29	27	40	53	42	40	40	40	40	40	40	40	40.18±5.84
BG-30	28	40	52	43	40	40	40	40	40	40	40	40.27±5.44

Table 4.2.9: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of yield-based indices used to evaluate overall heat tolerance (Cont'd)

Genotype	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI	$\bar{R}$±SDR
BG-31	36	40	49	48	40	40	40	40	40	40	40	41.18±3.82
BG-32	42	35	29	40	36	35	32	36	35	32	32	34.91±3.73
BG-33	56	40	36	57	40	40	40	40	40	40	40	42.64±6.96
BG-34	52	39	28	45	38	38	36	38	39	36	36	38.64±5.95
BG-35	39	12	3	24	21	18	3	21	12	3	3	14.45±11.53
BG-36	21	8	11	9	8	8	9	8	8	9	9	9.82±3.82
BG-37	12	6	21	5	6	6	15	6	6	15	15	10.27±5.52
BG-38	13	29	38	20	24	26	35	24	29	35	35	28.00±7.58
BG-39	24	5	4	7	7	7	4	7	5	4	4	7.09±5.77
BG-40	18	30	33	25	28	27	34	28	30	34	34	29.18±4.85
BG-41	31	34	34	33	32	34	37	32	34	37	37	34.09±2.12
BG-42	41	15	1	28	26	22	1	26	15	1	1	16.09±13.81
BG-43	2	3	26	2	2	2	14	2	3	14	14	7.64±8.13
BG-44	14	25	32	19	20	23	29	20	25	29	29	24.09±5.47
BG-45	17	4	6	6	5	4	5	5	4	5	5	6.00±3.71
BG-46	45	28	12	35	31	31	20	31	28	20	20	27.36±8.99
BG-47	23	24	30	23	22	25	26	22	24	26	26	24.64±2.34
BG-48	1	40	58	29	40	40	40	40	40	40	40	37.09±13.69
BG-49	20	40	54	41	40	40	40	40	40	40	40	39.55±7.71
BG-50	22	36	45	32	34	36	39	34	36	39	39	35.64±5.71
BG-51	11	26	39	16	18	21	33	18	26	33	33	24.91±8.84
BG-52	35	40	50	47	40	40	40	40	40	40	40	41.09±4.01
BG-53	30	10	8	15	14	12	8	14	10	8	8	12.45±6.41
BG-54	15	11	24	10	10	10	21	10	11	21	21	14.91±5.66
BG-55	38	17	5	26	23	20	7	23	17	7	7	17.27±10.23
BG-56	37	16	9	22	19	17	11	19	16	11	11	17.09±7.79
BG-57	7	2	15	3	3	3	10	3	2	10	10	6.18±4.45
BG-58	6	22	41	8	11	14	30	11	22	30	30	20.45±11.33

Table 4.2.10: Correlation coefficient between fruit yield (Yp and Ys) of bottle gourd genotypes and stress tolerance indices

	Yp	Ys	TOL	MP	GMP	HM	SSI	STI	YI	YSI	RSI
Yp	1										
Ys	0.369**	1									
TOL	0.268*	-0.796**	1								
MP	0.732**	0.904**	-0.461**	1							
GMP	0.405**	0.983**	-0.755**	0.908**	1						
HM	0.396**	0.991**	-0.769**	0.909**	0.999**	1					
SSI	-0.156NS	-0.952**	0.886**	-0.770**	-0.927**	-0.936**	1				
STI	0.514**	0.968**	-0.669**	0.946**	0.960**	0.966**	-0.847**	1			
YI	0.369**	1.000**	-0.796**	0.904**	0.983**	0.991**	-0.953**	0.967**	1		
YSI	0.155NS	0.952**	-0.886**	0.770**	0.926**	0.936**	-1.000**	0.846**	0.952**	1	
RSI	0.156NS	0.953**	-0.886**	0.771**	0.927**	0.937**	-1.000**	0.847**	0.953**	1.00**	1

Here, *=significant at 5 %, ** = significant at 1 % levels of probability and NS=non-significant.

Here, Yp= Yield under optimum condition, Ys=Yield under stress, TOL= Tolerance index, MP= Mean productivity, GMP= Geometric mean productivity, HM= Harmonic Mean, SSI= Stress susceptibility index, STI= Stress tolerance index, YI= Yield index, YSI= Yield stability index, RSI= Relative stress index

(Jha *et al.,* 2018) which matched with current findings. These associations suggested that these criteria were more successful in identifying genotypes with high yields under different conditions. Farshadfar *et al.* (2013) also reported strong positive correlations between MP, GMP, HM, YSI under both normal and heat stress conditions.

MP exhibited a strong and positive association with GMP, YI, HM, and STI but was negatively correlated with TOL and SSI. Similarly, GMP had significant positive association with MP, HM, STI, YI, YSI and RSI, but a high and negative correlation was exhibited with TOL and SSI. The heat stress tolerance index (STI) had a negative association with TOL and SSI, but a strong positive correlation with MP, GMP, STI, and YI. Importantly, YI exhibited a favoured associations with MP, GMP, HM, and STI, but a significant negative correlation with TOL and SSI. Lamba *et al.,* (2023) and Jha *et al.,* (2018) revealed a positive and significant correlation with MP, GMP, STI, and YI, but adversely associated with TOL and SSI in heat tolerance wheat and chickpeas. The results was also in agreement with the findings of drought tolerance in wheat (Anwar *et al.,* 2011) and chickpeas (Jha *et al.,* 2016). Both TOL and SSI had significant negative relationships with all of the stress tolerance indices, whereas SSI and TOL had a strong positive correlation (0.886). High positive associations with SSI and TOL and negative correlations with all other heat stress indicators were also reported Jha *et al.,* (2018) in chickpea indices. revealed a Substantial positive correlation between TOL and SSI, but a negative correlation with other stress indicators for wheat determined by several researchers (Farshadfar *et al.,* 2013; Anwar *et al.,* 2011; Lamba *et al.,* 2023), which was consistent with the findings of this investigation.

4.2.4.4 Principal component and biplot analysis

To find stress tolerant genotypes, principal component analysis (PCA) was performed utilizing correlation matrix with fruit yield (Yp and Ys) and heat stress tolerance indices. The principal components with an Eigen value greater than one were regarded superior components since they represented the most variation among all the attributes (Zopluoglu and Davenport, 2017). Among the thirteen principal components (PCs), the first two components with an eigen value >1.0 contributed maximum variation i.e. 98.39% (Table 4.2.11). The first two principal components (PC1 and PC2) contributed to the variations by 83.89 % and 14.5% of heat tolerance indices (Table 4.2.11). Farshadfar *et al.,* (2013) recorded 99.6% variations and Mashilo *et al.,* (2017) recorded 99.72% of total variations

in wheat and bottle gourd, respectively. The first component PC1, explained the significant positive association with Ys, MP, GMP, HM, STI, YI, and YSI but had a negative correlation with TOL and SSI. Thus, PC1 regarded as a stress tolerance component. The second component (PC2) was identified to be the heat susceptibility component since it explained a greater correlation with TOL, SSI, and Yp. This method was also utilized by Poudel *et al.* (2024), Lamba *et al.* (2023), and Devi *et al.* (2021) to categorize the components of wheat under heat stress. Moreover, the most appropriate criteria are to select stable genotypes with high PC1 and low PC2 values, and vice versa (Ullah *et al.*, 2022). Thus, genotypes BG-32, BG-29, BG-49, BG-04, and BG-26 recorded low PC1 values and high PC2 values, indicating that these genotypes produced low fruit yield and heat sensitivity and were therefore these genotypes were not recommended for cultivation. While genotypes BG-45, BG-57, BG-02, and BG-43 were found to have higher PC1 values with lower PC2 values regarded as superior with stable and tolerant genotypes under both normal and heat stress conditions and might recommended for cultivation. Poudel *et al.* (2024) and Lamba *et al.,* (2023) employed this approach to identify stable genotypes.

The biplot analysis was performed to depict the association between heat tolerance yield based indices and genotypes utilizing the first two components. According to Yan and Kang (2002), biplot indices are regarded as independent when the angle between their vectors is larger than 90 degrees, negatively connected when the angle is greater than 90 degrees, and positively associated when the angle is less than 90 degrees. The biplot displayed that Yp and Ys were positively connected with MP, GMP, HM, STI, YI, and YSI, while Ys was negatively correlated with TOL and SSI, as evidenced by the obtuse and acute angles between their vectors respectively (Figure 4.2.4). Lamba *et al.,* (2023) and Jha *et al.,* (2018) depicted these types relationship among indices using biplots for heat tolerance in wheat and chickpeas, respectively. Devi *et al.,* (2021) also illustrated positively associated with MP, GMP, STI as acute angles between their vectors while negative correlation with TOL and SSI as their vector showed obtuse angle in wheat grain yield under stress conditions.

Table 4.2.11: Principal component analysis showing eigenvectors, eigenvalues, and variability

Factors	PC1	PC2
Yield under optimum condition (Yp)	0.116	0.737
Yield under heat stress (Ys)	0.329	0.017
Tolerance index (TOL)	-0.265	0.462
Mean productivity (MP)	0.295	0.352
Geometric mean productivity (GMP)	0.325	0.054
Harmonic Mean (HM)	0.327	0.044
Stress susceptibility index (SSI)	-0.318	0.170
Stress tolerance index (STI)	0.314	0.165
Yield index (YI)	0.329	0.017
Yield stability index (YSI)	0.318	-0.170
Relative stress index (RSI)	0.318	-0.170
Eigenvalue	9.23	1.60
Variability	83.89	14.50
Cumulative	83.89	98.39

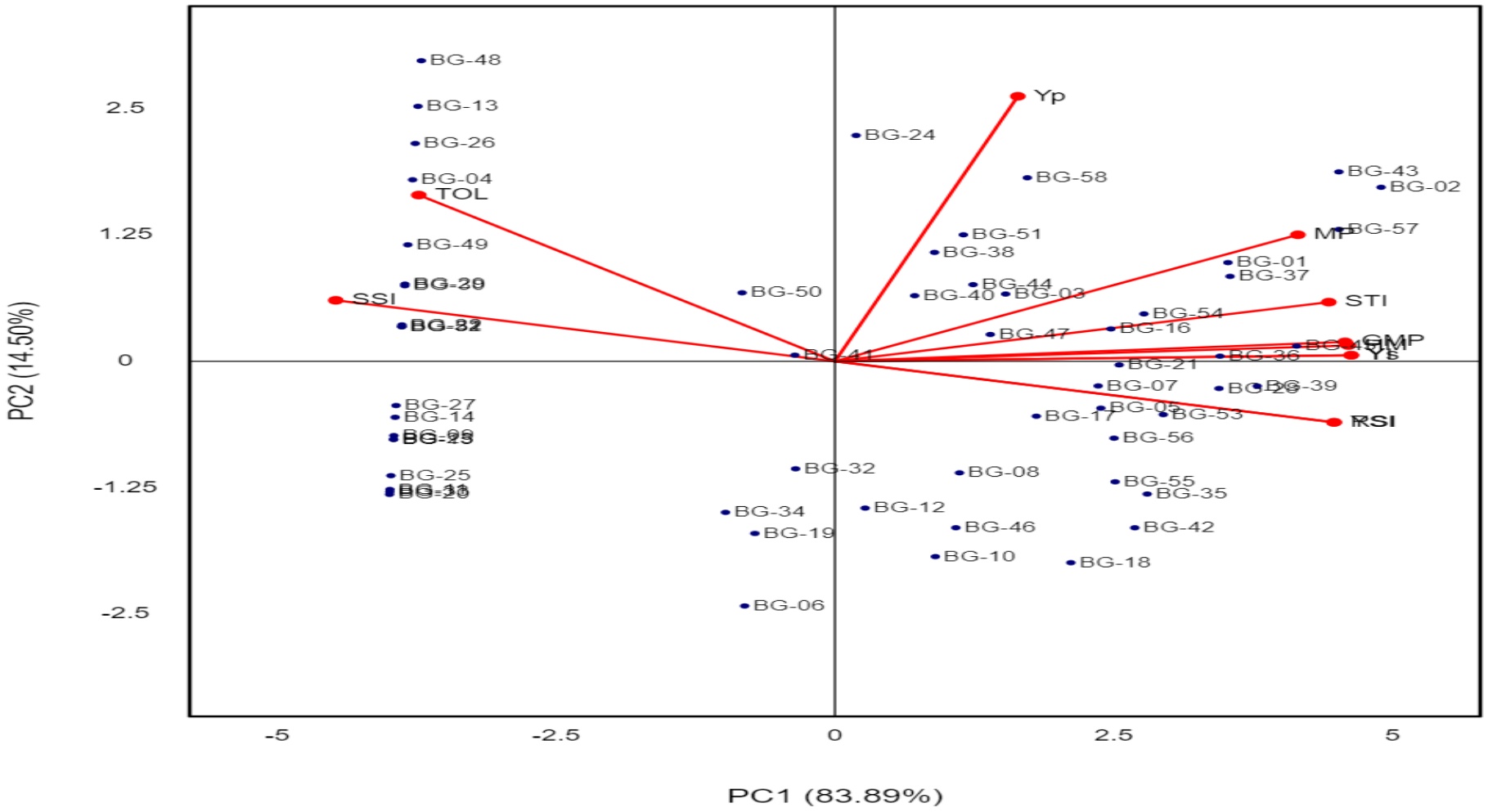


Figure 4.2.4: Biplot showing relationship among the various heat stress indices of 58 bottle gourd genotypes under heat stress

4.2.5 Ranking of yield and contributing traits for heat tolerance

The combined stress tolerance indices ranking of yield and its major contributing traits of fruit diameter, number of fruits per plant, fruit weight, and overall yield revealed substantial genotypic variation in heat tolerance among the 58 evaluated bottle gourd genotypes. The mean rank ($\bar{R}$) and standard deviation of ranks (SDR) provided a comprehensive measure of combined performance and stability under heat stress. The combined ranking and their mean ranks and standard deviations of rank presented in Table 4.2.12.

Among the examined genotypes, like BG-57 ($\bar{R}$ = 7.70), BG-45 ($\bar{R}$ = 9.16), BG-36 ($\bar{R}$ = 10.95), BG-39 (10.14), BG-02 (11.07), BG-37 (12.07), and BG-42 (13.07), were consistently exhibited lower ranked among the genotypes, indicating superior adaptability under high temperature and high tolerance to heat. In addition, BG-36 possessed the lower overall rank ($\bar{R}$ = 10.95) with minimal rank fluctuation (SDR = 1.01) across all traits, supported by the uniformly strong rankings. This stability suggests that BG-36 displayed a balanced contribution of fruit size, fruit number, fruit weight, and final yield even under high-temperature stress conditions. Therefore, BG-36, BG-39, BG-45, and BG-57, along with lower ranks, also possessed minimal SDR values, further confirming their tolerance stability and consistency across traits. Moreover, moderately ranked genotypes, including BG-53, BG-54, BG-21, BG-16, BG-43, BG-28, BG-55, and BG-56, exhibited acceptable performance with moderate variability across traits. These genotypes possessed yield potential under heat but showed some fluctuations, especially in fruit number or fruit weight, suggesting partial or medium tolerance rather than full resilience, and these genotypes possessed a combined rank less than twenty ($\bar{R} \leq 20$) and were marked as tolerant to heat stress.

In contrast, several genotypes, such as BG-09, BG-11, BG-14, BG-15, BG-20, BG-22, BG-23, BG-25, BG-27, BG-30, BG-31, BG-33, BG-49, and BG-52, consistently ranked higher, with mean ranks exceeding 40. These lines showed poor performance for all contributing traits under heat stress, accompanied by very low SDR values that reflect their uniform but consistently poor adaptability. Their poor rankings across yield and component traits suggested severe sensitivity to reproductive heat stress, leading to reduced fruit set, impaired fruit development, and significant yield loss. The combined ranking based on yield and contributing traits revealed that the ranking clearly distinguished highly heat-tolerant genotypes BG-57, BG-45, BG-36, BG-39, BG-02, and

Table 4.2.12: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of Yield and Key-contributing traits-based indices used to evaluate overall heat tolerance

Genotype	Fruit diameter (cm)	Number of fruits per plant	Fruit weight (kg)	Yield (t ha^{-1})	SR	$\bar{R}$±SDR
BG-01	24.73	13.82	19.82	10.09	68.45	17.11±6.47
BG-02	21.55	8.00	9.00	5.73	44.28	11.07±7.12
BG-03	27.09	25.45	34.45	22.18	109.18	27.30±5.19
BG-04	41.55	38.45	40.64	38.45	159.09	39.77±1.57
BG-05	9.00	28.73	27.27	17.18	82.18	20.55±9.25
BG-06	39.73	23.09	33.27	36.18	132.27	33.07±7.16
BG-07	23.55	13.36	24.55	18.45	79.91	19.98±5.15
BG-08	20.82	12.73	17.36	27.64	78.55	19.64±6.28
BG-09	41.55	41.55	41.64	42.18	166.91	41.73±0.31
BG-10	14.45	27.82	13.27	28.09	83.64	20.91±8.15
BG-11	39.27	43.00	40.36	42.55	165.18	41.30±1.77
BG-12	24.36	34.45	14.91	31.64	105.36	26.34±8.73
BG-13	41.00	39.55	38.27	37.82	156.64	39.16±1.43
BG-14	41.09	42.91	38.91	41.91	164.82	41.20±1.70
BG-15	39.64	43.09	38.64	42.36	163.73	40.93±2.13
BG-16	26.09	15.00	17.82	17.09	76.00	19.00±4.88
BG-17	24.64	18.00	32.45	23.82	98.91	24.73±5.94
BG-18	35.64	9.36	26.27	19.18	90.45	22.61±11.11
BG-19	39.00	33.27	25.55	36.36	134.18	33.55±5.82
BG-20	38.64	41.09	43.09	42.73	165.55	41.39±2.03
BG-21	20.82	21.00	10.18	16.00	68.00	17.00±5.10
BG-22	42.55	40.27	41.09	41.00	164.91	41.23±0.95
BG-23	43.18	42.73	40.00	42.27	168.18	42.05±1.41
BG-24	32.64	30.82	19.36	29.91	112.73	28.18±5.99
BG-25	42.91	42.27	42.64	42.64	170.45	42.61±0.26
BG-26	42.27	39.82	38.09	38.18	158.36	39.59±1.96
BG-27	42.00	42.45	39.73	41.82	166.00	41.50±1.21
BG-28	35.64	12.73	5.73	9.73	63.82	15.95±13.43
BG-29	37.55	40.64	38.73	40.18	157.09	39.27±1.41
BG-30	40.82	41.55	38.82	40.27	161.45	40.36±1.15

Table 4.2.12: Rank, rank mean ($\bar{R}$) and standard deviation of ranks (SDR) of yield and key-contributing traits-based indices used to evaluate overall heat tolerance (Cont'd)

Genotype	Fruit diameter	Number of fruits per plant	Fruit weight (kg)	Yield (t ha^{-1})	SR	$\bar{R}$±SDR
BG-31	39.18	42.18	40.00	41.18	162.55	40.64±1.32
BG-32	29.00	36.64	19.18	34.91	119.73	29.93±7.88
BG-33	39.91	39.82	42.73	42.64	165.09	41.27±1.63
BG-34	39.09	37.64	27.82	38.64	143.18	35.80±5.35
BG-35	12.09	5.45	27.73	14.45	59.73	14.93±9.34
BG-36	11.00	10.73	12.27	9.82	43.82	10.95±1.01
BG-37	9.09	13.36	15.55	10.27	48.27	12.07±2.94
BG-38	26.82	25.18	13.36	28.00	93.36	23.34±6.75
BG-39	12.09	11.73	9.64	7.09	40.55	10.14±2.30
BG-40	12.00	26.09	28.64	29.18	95.91	23.98±8.10
BG-41	18.55	32.36	22.18	34.09	107.18	26.80±7.61
BG-42	5.45	16.09	17.18	16.09	54.82	13.70±5.52
BG-43	22.45	11.09	30.27	7.64	71.45	17.86±10.42
BG-44	28.82	35.27	21.18	24.09	109.36	27.34±6.15
BG-45	11.64	14.36	4.64	6.00	36.64	9.16±4.61
BG-46	13.00	29.91	17.82	27.36	88.09	22.02±7.95
BG-47	25.55	25.18	34.82	24.64	110.18	27.55±4.86
BG-48	41.55	39.55	37.91	37.09	156.09	39.02±1.97
BG-49	42.45	41.09	38.91	39.55	162.00	40.50±1.59
BG-50	30.82	34.00	30.00	35.64	130.45	32.61±2.65
BG-51	20.27	30.09	20.27	24.91	95.55	23.89±4.68
BG-52	42.73	41.55	40.00	41.09	165.36	41.34±1.13
BG-53	15.36	5.55	24.00	12.45	57.36	14.34±7.64
BG-54	6.55	10.64	28.00	14.91	60.09	15.02±9.30
BG-55	6.91	17.82	21.73	17.27	63.73	15.93±6.33
BG-56	16.18	19.00	14.73	17.09	67.00	16.75±1.79
BG-57	2.82	7.91	13.91	6.18	30.82	7.70±4.65
BG-58	10.64	7.18	36.82	20.45	75.09	18.77±13.28

Here, SR= Sum of rank, SDR= Standard deviation of ranks

BG-42, which displayed stable performance across all the yield component traits under high temperature stress. These genotypes represent promising candidates for breeding programs aimed at enhancing heat resilience in bottle gourd. The results further showed the necessity of combining multiple trait-based indices rather than depending on yield.

4.2.6 Cluster analysis based on stress tolerance indices

The cluster analysis categorized genotypes into three clusters based on stress tolerance indices trends. Among the cluster, cluster 2 possessed the twenty-one (21) genotypes with the highest MP, GMP, HM, STI, YI, and YSI, indicating strong performance and desirable traits categorized as tolerant (Table 4.2.13). Similarly, cluster 3 exhibited medium heat tolerance indices and consisted 18 genotypes classified as semi-tolerant (Table 4.2.13). Consequently, cluster 1 had the highest TOL and SSI values, but lower MP, GMP, HM, YI values, with 19 genotypes suited only for optimum condition (winter), indicating that they were susceptible genotypes (Figure 4.2.5). Naghavi *et al.,* (2013) grouped corn genotypes for drought tolerance into three clusters, Khalili *et al.,* (2012) categorized canola genotypes into three groups, while Lamba *et al.* (2023) classified wheat genotypes into seven clusters, which validated selection through clustering of studied genotypes.

Table 4.2.13: Clustering of bottle gourd genotypes based on heat tolerance indices

Cluster	Genotypes	No of genotypes
Cluster I	BG-04, BG-09, BG-11, BG-13, BG-14, BG-15, BG-20, BG-22, BG-23, BG-25, BG-26, BG-27, BG-29, BG-30, BG-31, BG-33, BG-48, BG-49, BG-52	19
Cluster II	BG-01, BG-02, BG-05, BG-07, BG-16, BG-17, BG-18, BG-21, BG-28, BG-35, BG-36, BG-37, BG-39, BG-42,BG-43, BG-45, BG- 53, BG-55, BG-56, BG-54, BG-57	21
Cluster III	BG-03, BG-06, BG-8, BG-10, BG-12, BG-19, BG-24, BG-32, BG-34, BG-38, BG-40, BG-41, BG-44, BG-46, BG-47, BG-50, BG-51, BG-58	18

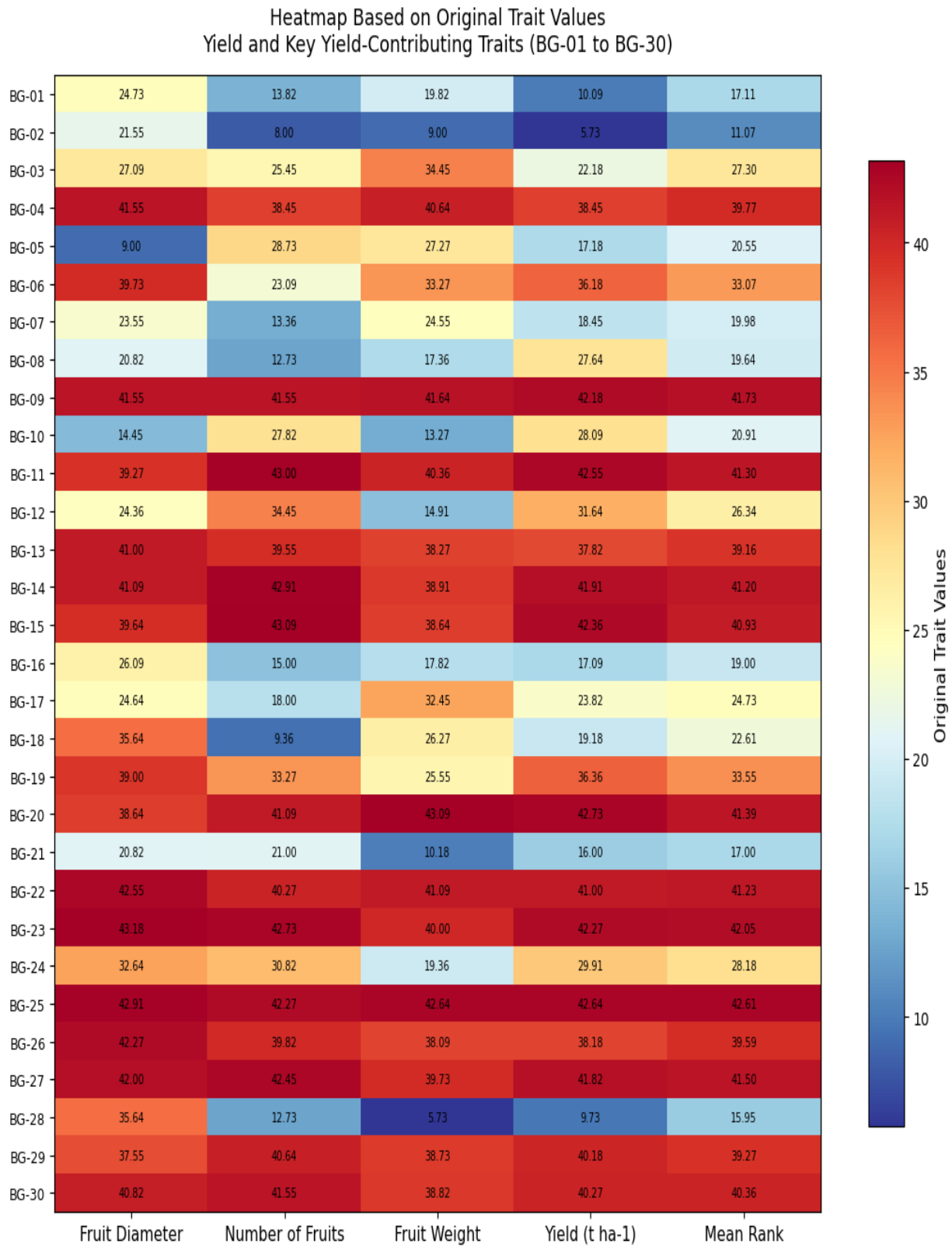


Figure 4.2.5: Heat map showing ranking of key yield contributing traits stress tolerance indices

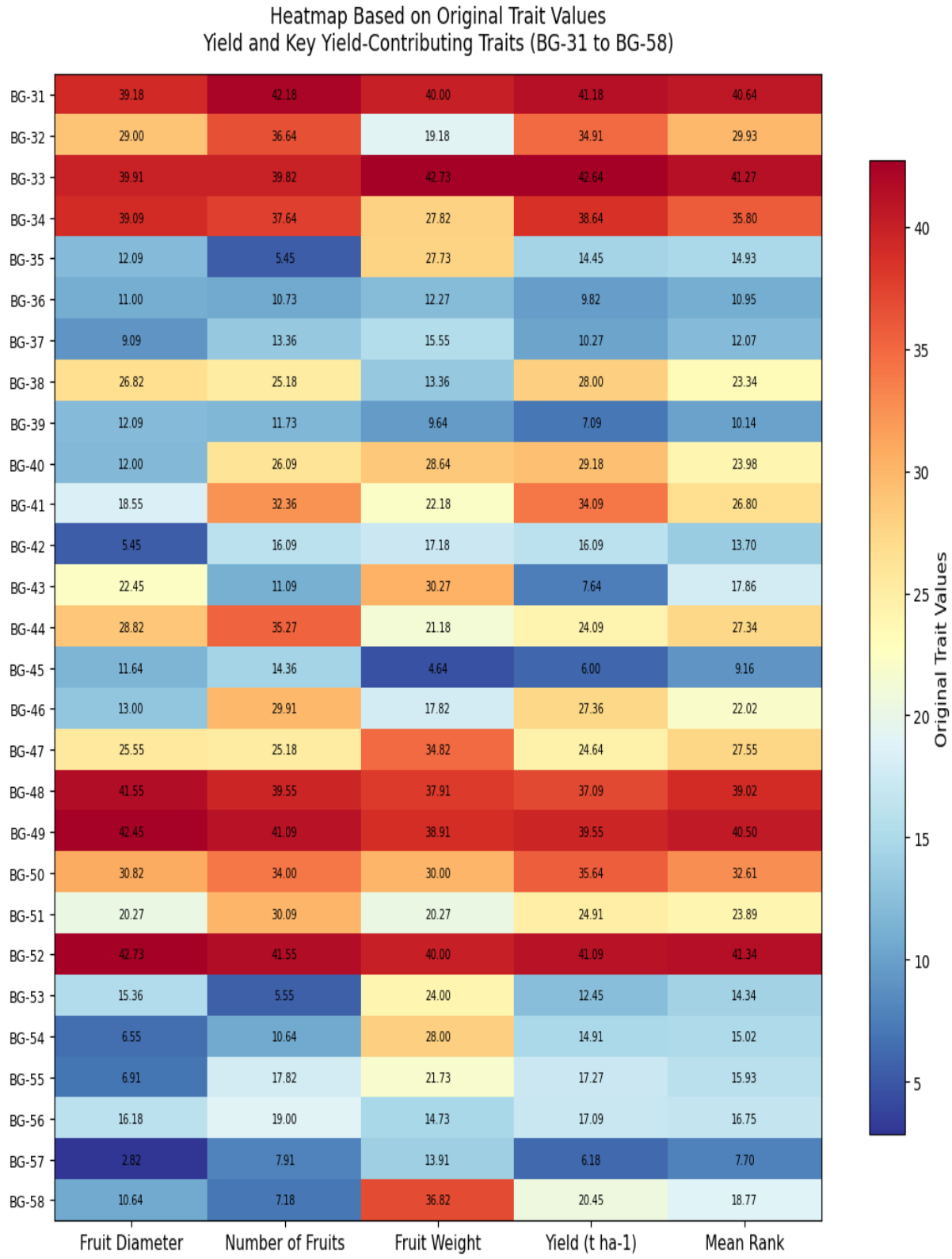


Figure 4.2.5: Heat map showing ranking of key yield contributing traits stress tolerance indices (cont'd)

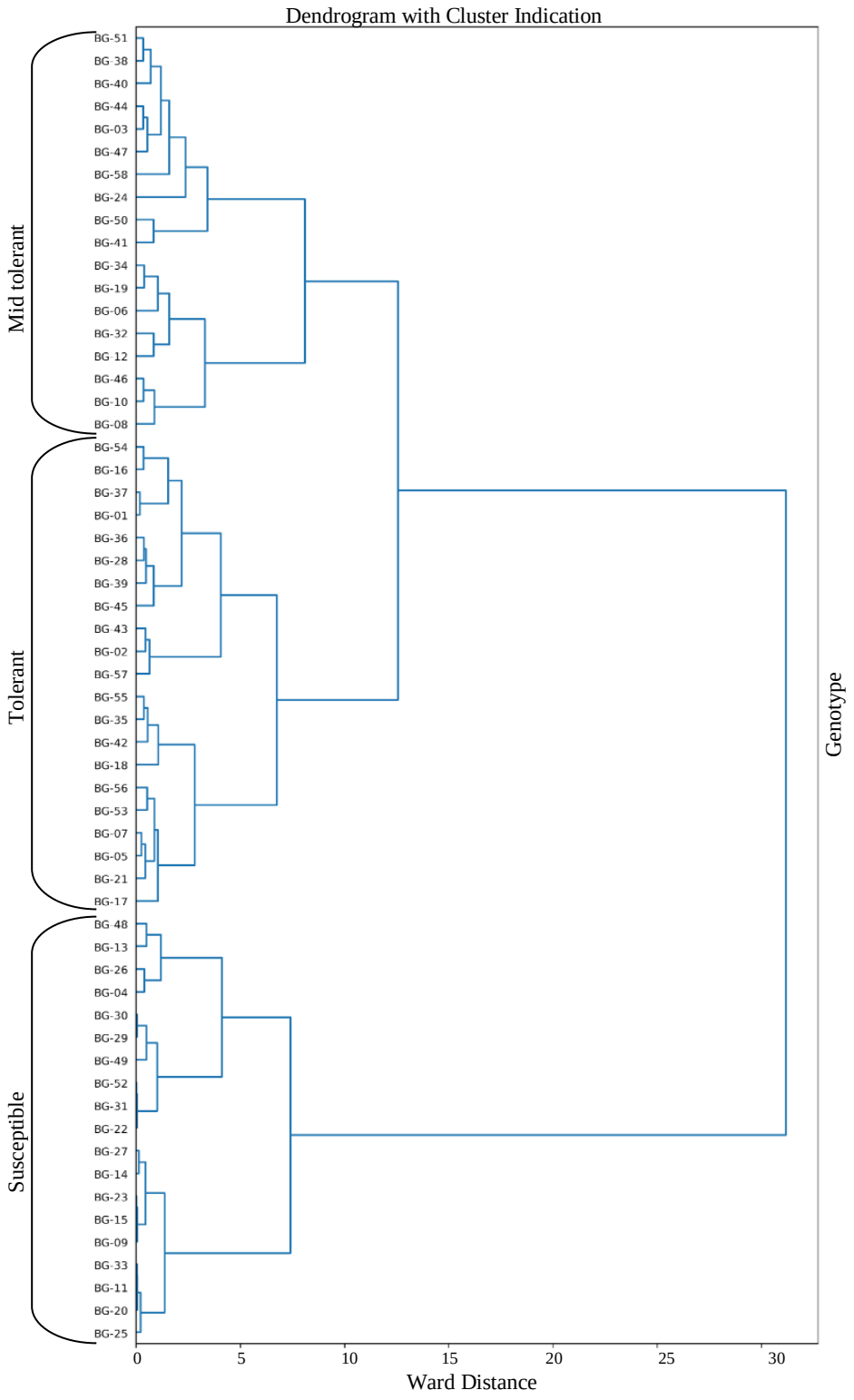
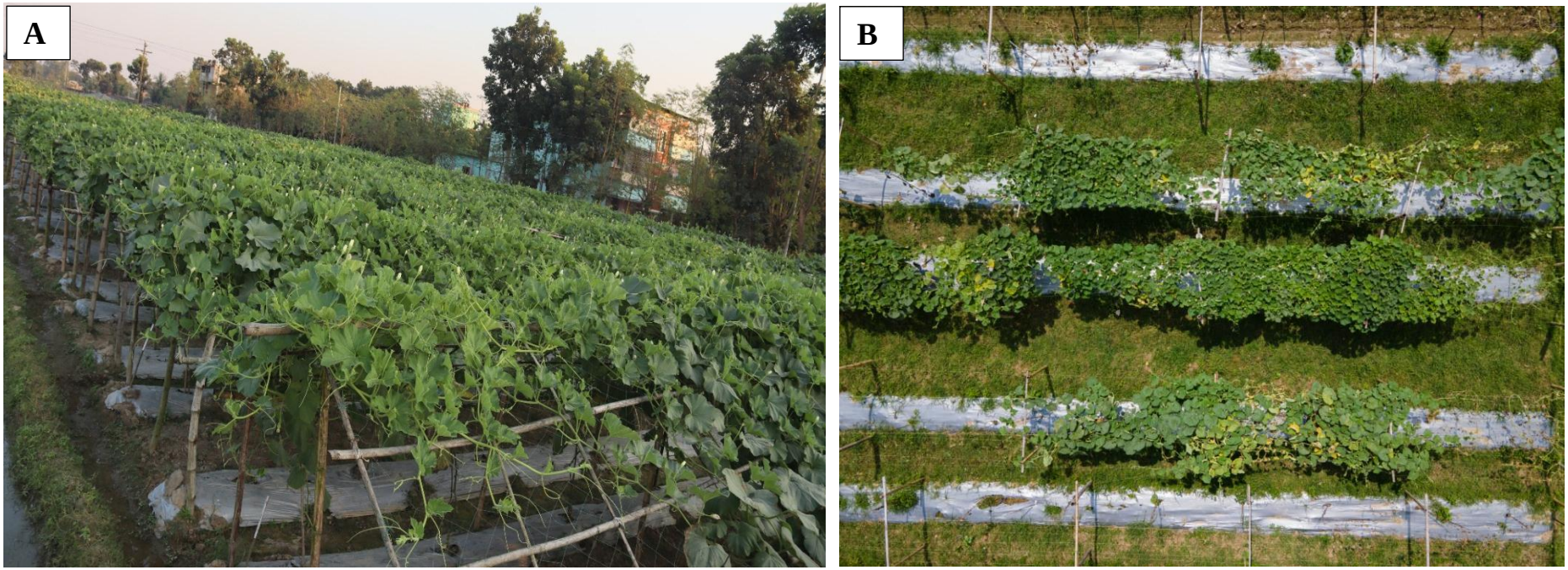


Figure 4.2.6. Dendrogram using Ward method among groups showing classification of cultivars based on heat tolerance



A) Field view at optimum season sowing condition

B) Aerial field view under heat stress sowing condition

Plate 4.2.1 Pictorial view of experimental plot during (A) optimum and (B) heat stress conditions



Plate 4.2.2 Aerial view of experimental field of 58 bottle gourd genotypes under heat stress conditions



A) Fruit morphotypes of 58 genotypes at optimum sowing conditions



B) Fruit morphotypes of tolerant and mid-tolerant genotypes under heat stress condition

Plate 4.2.3: Fruit morphotypes of bottle gourd genotypes under (A) optimum and (B) heat stress sowing conditions

4.3 Experiment-III: Selection of Heat-Tolerant Inbred Lines based on Combining Ability Using Line × Tester Analysis in Bottle Gourd

The line x tester analysis provides useful information on the identification of superior parents and crosses with their general combining ability effects. Combining ability studies in cross-pollinated crops are helpful for selecting the best combining parents, which, when crossed and generate more desirable recombinants, and such studies additionally provide knowledge on the nature and extent of gene activity in the inheritance of fruit yield and its components. The combining ability studies in diverse environments provide precise knowledge because environmental factors play a significant role in determining the magnitude of gene effects.

Therefore, the current study was conducted for the combining ability analysis in bottle gourd over environments utilizing Line × Tester analysis during heat stress during summer season in field conditions. Earliness and fruit characteristics are the most important factors for selection. Traits such as days to first female flower opening, days to first edible fruit harvest, fruit length, fruit diameter, fruit weight, number of fruits per plant, and yield per plant were analyzed using Line × Tester in the present investigation.

4.3.1 Analysis of variances

The analysis of variance for the experiment with forty (40) hybrids with twenty lines (20) and two (2) testers for eight studied traits, viz., days to 1st female flower appearance, node number of 1st female appearance, days to 1st fruit harvest, number of fruits per plant, fruit weight, fruit length, fruit diameter, and yield, was performed to determine the significance of variances among the treatments using the "F" test. Analysis of variance revealed significant differences existed among the lines, testers, and interactions for all the traits under study (Table 4.3.1). Thus, it suggested the existence of inherent differences between the genotypes studied.

The results revealed that replication effects were non-significant for all traits except for fruit weight, while block effects were only significant for fruit yield per plant, indicating minimal environmental variability and effective experimental design. This suggests that observed phenotypic differences were primarily due to genotypic variation rather than environmental factors. The similar findings were also reported by Patel *et al.* (2023), Masud *et al.* (2021), and Khot *et al.* (2021). Analysis of genetic effects revealed significant differences among lines for reproductive traits, including days to first female flower opening and node number

of the first female flower, as well as yield-related traits such as fruit weight, length, diameter, and yield per plant. Additionally, testers showed notable benefits for fruit traits and maturity traits. The significant line × tester interactions for flowering, maturity, and fruit traits indicated that both additive and non-additive gene actions contributed to trait expression. The findings were consistent with earlier studies by Janaranjani *et al.* (2016), Kumar *et al.* (2018), and Yadav *et al.* (2025), illustrating the influence of complex genetic mechanisms on these agronomic traits.

4.3.2 General combining ability (GCA) effects of the parents

General combining ability (GCA) largely reflects additive genetic variance and is therefore a key criterion for identifying superior parents for hybridization (Sprague & Tatum, 1942). Estimates of GCA provide essential information on the genetic potential of parental lines and their ability to transmit favorable alleles to progeny, facilitating the development of superior segregants and widely adapted hybrids (Roy *et al.*, 2009). A high and significant GCA effect indicates the presence of desirable additive genes, whereas low or non-significant GCA effects suggest limited deviation of a parent from the overall mean performance of crosses.

In the present study, GCA effects of 20 lines and 2 testers, along with SCA effects of 40 crosses, were estimated for all traits across individual environments and on a pooled basis. Based on pooled GCA estimates, parents were categorized as good, average, or poor combiners following Griffing (1956 a). Hybridization among parents with significant GCA effects is expected to produce a higher proportion of superior progeny, thereby enhancing selection efficiency and contributing to the effective development of high-performing commercial hybrids. The general combining ability (GCA) effects of the parents for earliness, fruit size, and yield contributing traits were depicted in Table 4.3.2.

Earliness traits

For days to first female flower appearance, several hybrids exhibited significant strong and negative general combining ability (GCA) effects. Among the studied lines BG-54 (-3.89), BG-36 (-2.60), BG-16 (-2.53), and BG-35 (-2.42) exhibited the strongest negative GCA effects, making them desirable parents for early flowering that is regarded as good general combiners. Conversely, lines BG-57, BG-43, BG-37, and BG-18 showed positive GCA effects, categorized them as poor combiners.

Table 4.3.1: Analysis of variance for Line × Tester analysis of yield and its component traits in bottle gourd

Source of variation	DF	Days to first female flower appearance	Node of first female flower appearance	Days to first edible fruit harvest	Number of fruits per plants	Fruit weight (kg)	Fruit length (cm)	Fruit diameter (cm)	Yield/plant (kg)
Replication	1	0.33	2.09	5.01	2.01	0.04*	6.79	0.44	1.40
Block within replication	12	0.76	5.89	0.49	1.82	0.01	2.50	0.53	2.68*
Crosses	39	22.43**	9.10**	20.75**	20.61**	0.04**	97.32**	7.19**	68.82**
Lines	19	20.12**	8.68*	20.29**	20.88**	0.05**	102.43**	5.73**	80.01**
Testers	1	54.45**	10.88	72.71**	4.97	0.04*	898.40**	94.92**	49.63**
Lines × testers	19	23.06**	9.44*	18.47**	21.16**	0.02**	50.05**	4.03**	58.64**
Error	27	1.17	3.79	2.03	1.08	0.01	4.41	0.72	1.20

Here, *p≤0.05 and **p≤0.01 level of probability.

Table 4.3.2 General combining ability (GCA) effects of lines and testers for earliness and fruit yield components in bottle gourd

Genotypes	Days to first female flower appearance	Node of first female flower appearance	Days to first edible fruit harvest	Number of fruits per plants	Fruit weight (kg)	Fruit length (cm)	Fruit Diameter (cm)	Yield/Plant (kg)
				Lines				
BG-01	0.69*	-0.76	0.82*	-2.01**	0.04*	8.05**	-0.89**	1.11
BG-02	-1.46**	-0.20	-1.93**	1.63**	-0.17**	5.07**	-0.58*	2.36**
BG-05	1.04*	-1.27*	1.96**	0.74*	-0.02	-7.22**	0.75*	0.62
BG-07	-2.17**	0.34	-3.68**	-0.97*	0.16**	0.75	-0.23	-0.41
BG-16	-2.53**	-0.41	-1.96**	1.53**	0.19**	5.64**	-1.43**	4.28**
BG-18	2.22**	-0.64	3.89**	-6.15**	-0.11**	3.32**	-1.46**	-12.11**
BG-21	-1.03*	2.03**	-1.96**	2.38**	0.10**	-0.94	1.26**	7.16**
BG-28	0.47	-2.27**	0.07	-0.73*	0.03	7.25**	-1.38**	-0.43
BG-35	-2.42**	0.19	-3.21**	1.93**	0.08*	1.21*	-0.70*	3.87**
BG-36	-2.60**	1.40*	-2.14**	-0.37	0.05*	4.17**	-0.78*	0.60
BG-37	2.37**	3.75**	-0.07	-2.69**	-0.07*	-3.64**	0.56*	-8.93**
BG-39	1.36**	-0.05	2.18**	-2.43**	-0.04*	4.25**	-0.36	-4.42**
BG-42	0.90*	0.45	-0.21	1.03*	0.04*	-6.24**	1.53**	2.79**
BG-43	3.65**	1.34*	3.04**	1.12**	-0.01	-3.02**	-0.04	0.59
BG-45	0.97*	-1.55*	0.32	2.60**	0.14**	0.38	-0.56*	0.84
BG-53	-1.88**	1.66*	0.07	-0.37	-0.09**	3.95**	-1.56**	-2.56**
BG-54	-3.89**	-1.23*	-1.50**	4.03**	-0.19**	-6.44**	0.16	4.76**

Table 4.3.2: General combining ability (GCA) effects of lines and testers for earliness and fruit yield components in bottle gourd (cont'd)

Genotypes	Days to first female flower appearance	Node of first female flower appearance	Days to first edible fruit harvest	Number of fruits per plants	Fruit weight (kg)	Fruit length (cm)	Fruit Diameter (cm)	Yield/Plant (kg)
BG-55	-1.31**	-1.23*	-1.25*	-1.37**	-0.11**	-5.25**	1.58**	-1.28*
BG-56	1.54**	0.12*	1.50**	0.49	0.07*	-6.13**	2.22**	1.38*
BG-57	4.08**	-1.66*	4.07**	-0.37	-0.08*	-5.14**	1.94**	-0.18
S.E. gca	0.54	0.97	0.71	0.52	0.04	1.05	0.43	0.55
C.D. (5%)	1.11	2.00	1.46	1.07	0.09	2.15	0.87	1.12
C.D. (1%)	1.50	2.70	1.98	1.44	0.12	2.91	1.18	1.52
Testers								
BG-03	0.83**	0.37	0.95**	0.25	0.02	3.35**	-1.09**	0.79**
BG-58	-0.83**	-0.37	-0.95**	-0.25	-0.02	-3.35**	1.09**	-0.79**
S.E. tester	0.17	0.31	0.23	0.16	0.01	0.33	0.13	0.17
C.D. (5%)	0.35	0.63	0.46	0.34	0.03	0.68	0.28	0.36
C.D. (1%)	0.47	0.85	0.62	0.46	0.04	0.92	0.37	0.48

Here, *$p \leq 0.05$ and **$p \leq 0.01$ level of probability.

Masud *et al.* (2021) also reported two among female parents as good combiners for their significant negative GCA effects. Ahmad *et al.* (2022) recorded GCA from -2.92 for IC-398541 to 3.99 in IC-336820 for days to 50% flowering, which was consistent performance with the present findings.

For node number at which first female flower appearnce, a genotype bearing the first female flower at a lower node number was considered to be desirable in bottle gourd. Among the examined lines BG-28 (-2.27), BG-57 (-1.66), BG-45 (-1.57), and BG-05 (-1.27) displayed significant negative GCA values, categorizing them as good general combiners for early flowering. In contrast, lines BG-37 (3.75), BG-18 (2.03), BG-53 (1.66), BG-36 (1.40), and BG-43 (1.34) exhibited positive GCA effects, suggesting a delay in flowering classified as a poor combiner. Patel *et al.* (2023) identified the lines BRBG-65 (-0.93), BRBG-22-1 (-0.8), and tester Rajendra Chamatkar (-0.72) as good general combiners for their significant negative GCA effects, which were consistent with current findings. Sharma *et al.* (2002) illustrated that the parent GH-13 was the best combiner for the node to first female flowering, vine length, and average fruit weight.

Negative GCA values suggest enhanced early-flowering potential for breeding programs. The GCA effects and contribution of days to first edible fruit harvest presented in Figure 4.3.1. Negative general combining ability (GCA) effects for days to first edible fruit harvest was identified as significant economic traits for bottle gourd. Negative and significant GCA values were observed in lines BG-07 (-3.68), BG-35 (-3.21), BG-36 (-2.14), BG-16 (-1.96), and BG-21 (-1.96). These genotypes were identified as effective general combiners and were early maturing for edible fruit harvest. The lines BG-57 (4.07), BG-18 (3.89), BG-43 (3.04), and BG-39 (2.18) exhibited significant positive GCA effects but were classified as poor general combiners due to their longer duration for the first edible fruit harvest. Similar findings of negative GCA effects among the parents were demonstrated by Masud *et al.* (2021) and Khot *et al.* (2021).

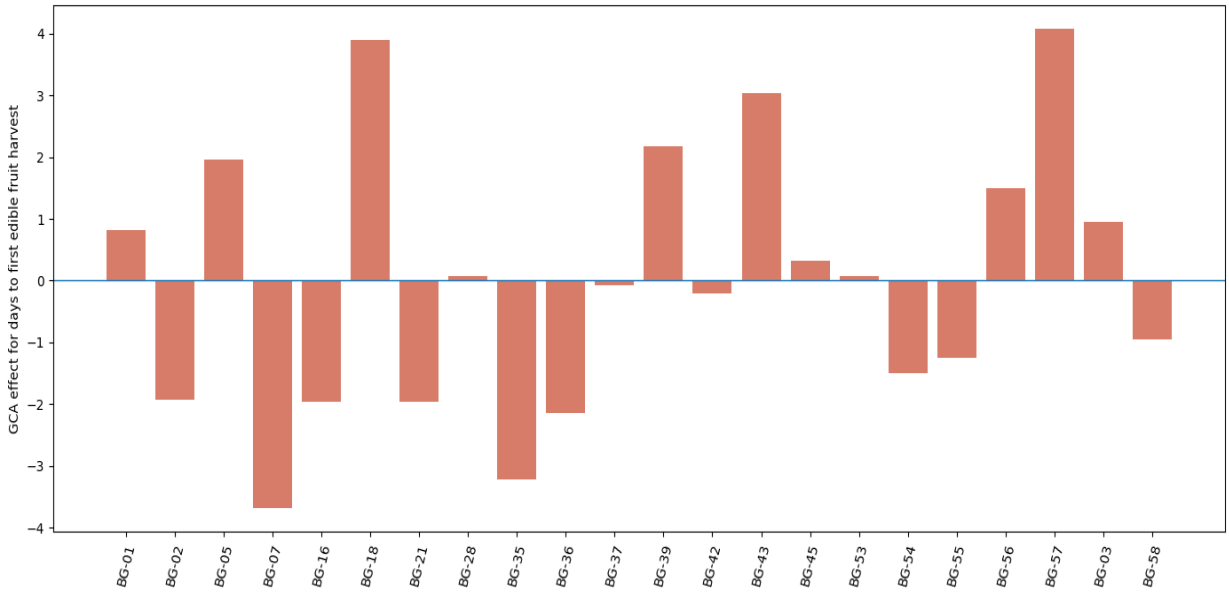


Figure 4.3.1. General combining ability (GCA) effects of parental lines and testers for days to first edible fruit harvest in bottle gourd

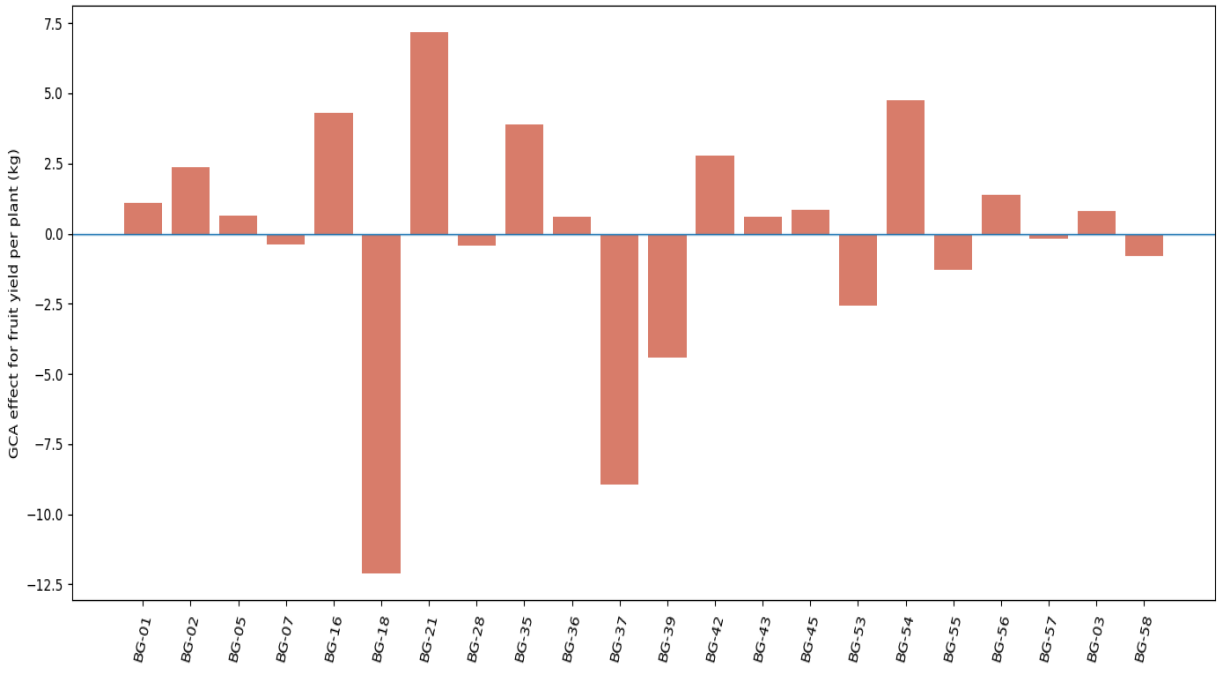


Figure 4.3.2. General combining ability (GCA) effects of parental lines and testers for fruit yield per plant in bottle gourd

Patel *et al.* (2023) reported contradictory results for days to first edible fruit harvest, with no substantial negative GCA effects observed for this trait. Sharma *et al.* (2002) showed KBG-16 was the best combiner for days to first female flower and days to first fruit picking. Among testers, BG-58 showed significant negative GCA effects for days to first female flower (-0.83), node at first female flower (-0.37), and days to first harvest (-0.95), identifying it as a superior tester for earliness, whereas BG-03 behaved as a late tester. Among them, BG-54 recorded the highest negative GCA effect for days to first female flower (-3.89) and node at first female flower (-1.23), indicating its superiority as an early flowering parent.

Fruit length and diameter

Fruit length and diameter are two of the most important features that determine the overall fruit shape and size and have a direct impact on yield. Among the evaluated lines, BG-01 (8.05) had the highest and most significant general combining ability (GCA) effects for fruit length, followed by BG-28 (7.25), BG-16 (5.64), BG-02 (5.07), BG-39 (4.25), and BG-36 (4.17), all of which were considered as good general combiners. On the contrary, the line BG-05 (-7.22) had the lowest and most significant GCA effects, followed by BG-54 (-6.44), BG-42 (-6.24), BG-56 (-6.13), and BG-55 (-5.25), which were regarded as poor general combiners. Beside this, for fruit diameter lines BG-56 (2.22) demonstrated the strongest positive and substantial GCA effects for fruit diameter, followed by BG-57 (1.94), BG-55 (1.58), and BG-42 (1.53) were marked as good general combiners. Whereas, lines BG-53 (-1.56), BG-18 (-1.46), BG-16 (-1.43), and BG-28 (-1.38) were recorded the lowest GCA effects and identified as being poor general combiners. Previous studies have reported wide variation in GCA effects for fruit length and fruit diameter in bottle gourd. Sharma *et al.* (2002) identified Arka Bahar and PSPL as good general combiners for fruit length and fruit diameter, respectively. Hadiya *et al.* (2020) observed GCA effects for fruit length ranging from –18.18 to 7.27 and for fruit diameter from –1.79 to 2.35, closely matching the trend of the present study. Similarly, Janaranjani *et al.* (2016) and Ahmad *et al.* (2022) reported both negative and positive GCA effects for fruit length, with several genotypes identified as good general combiners for fruit diameter. These reports collectively supported the present findings, confirming substantial genetic variability and the effectiveness of GCA-based selection for improving fruit size traits.

Yield contributing traits

Number of fruits per plant is one of the most crucial yield-contributing traits for bottle gourd. Among the lines, BG-54 (4.03) displayed the highest positive significant GCA effects, followed by lines BG-45 (2.60), BG-21 (2.38), BG-35 (1.93), BG-02 (1.63), and BG-16 (1.53), indicated that strong additive genetic control for number of fruits per plant and considered as good general combiners. In contrast, line BG-18 (-6.15) showed negative and significant GCA effects, followed by BG-37 (-2.69), BG-39 (-2.43), BG-01 (-2.01), and BG-55 (-1.37), which were marked as poor combiners for fruits per plant. Raut and Mishra (2015) also reported strong GCA effects for the number of fruits per plant in JBG15 (1.377), JBG12 (0.429), JBG5 (0.366) and JBG3 (0.360). Masud *et al.* (2021) reported parental lines 59-1-1-1(A)-7 and 62-12-1-2-2-2, which showed significantly positive GCA effects for fruits per plant. Sirohi and Rana (2008) reported parent P1 (Pusa Naveen) showed the highest GCA effects for the number of fruits per plant.

For fruit weight, lines BG-16 (01.9) had the greatest and most significant GCA effects, followed by BG-07 (01.6), BG-45 (0.14), and BG-21 (0.10), all of which were considered good general combiners. In contrast, lines BG-54 (-0.19), BG-02 (-0.17), BG-55 (-0.11), and BG-18 (-0.11) had the lowest GCA effects for single fruit weight and were classified as poor general combiners. Sharma *et al.* (2002) noted that for the node at the first female flower and average fruit weight, GH-13 was the best combiner. Sirohi and Rana (2008) found that parent P5 (Samrat Long) showed the highest GCA effects for fruit weight and total yield per plant. Yadav *et al.* (2025) reported the similar pattern of (-0.09-0.09) for pooled averaged fruit weight, and Masud *et al.* (2021) also showed identical ranges of GCA effects (-0.15 to 0.20) in bottle gourd. These results were inconsistent with the findings of the present study in relation to fruit weight.

Finally, for fruit yield per plant line, BG-21 (7.16) exhibited the most substantial positive GCA effects, succeeded by BG-54 (4.76), BG-16 (4.28), BG-35 (3.87), and BG-42 (2.79). These parental lines were identified as effective general combiners for fruit yield per plant. The lines exhibiting the lowest negative and significant GCA impacts were BG-18 (-12.11), BG-37 (-8.93), BG-39 (4.42), and BG-53 (-2.56), identified as ineffective general combiners for fruit yield per plant. These results revealed the reinforcing of the importance of additive gene action in yield improvement. The GCA effects for fruit yield

per plant were presented in Figure 4.3.2. These findings highlight the potential of high-GCA parents in breeding programs aimed at improving yield and related traits in bottle gourd. The identification of strong general combiners provides a valuable genetic resource for developing superior hybrids with enhanced productivity and desirable agronomic characteristics, as emphasized in modern crop breeding strategies (Hallauer *et al.*, 2010). Masud *et al.* (2021) presented the parental lines 59-1-1-1(A)-7 (2.16), 62-12-1-2-2-2 (0.93), and 62-12-1-1(A)-7 (0.92), which exhibited significantly positive general combining ability effects for yield per plant. Raut and Mishra (2015) reported the parents JBG15 (1.53), JBG14 (0.689), and JBG7 (0.382) exhibited strong positive GCA effects for yield.

4.3.3 Evaluation of parents based on mean performance

The mean performance of parental lines for all traits (Table 4.3.3) showed wide variation, confirming the ANOVA results and indicating substantial genetic diversity and strong breeding value among the parents. The morphotypes of the parental lines and testers are illustrated in Plate 4.3.1. The line BG-05 (48.86) exhibited the lowest and most favorable mean value for days to first female flower appearance, followed by BG-28 (48.93), BG-07 (50.50), BG-01 (51.29), and BG-53 (51.50). In contrast, the line BG-18 (64.57) demonstrated least desirable and highest mean value for days to first female flower opening, followed by BG-45 (61.64), BG-37 (60.50), BG-36 (58.93), and BG-39 (58.50) (Table 4.3.3). The lowest and most advantageous mean performance for node number at the first female flower opening was observed in BG-54 (14.50), succeeded by BG-55 (15.79), BG-02 (16.21), BG-39 (17.64), and BG-21 (17.67). The line BG-18 (33.86) exhibits the highest and least desired node number for initial female flower opening, followed by BG-56 (25.79), BG-16 (22.07), BG-57 (21.93), and BG-35 (21.50). The line BG-53 (61.00) exhibited the lowest and greatest favorable mean value for days to first edible fruit harvest, succeeded by BG-28 (61.50), BG-01 (62.14), BG-54 (62.14), and BG-05 (63.71). In later stages of harvest, BG-18 (75.79) ranked highest, followed by BG-45 (72.50), BG-39 (70.29), BG-37 (69.86), and BG-36 (69.43). Early-stage fruit bearing is a notable and advantageous characteristic for producers. Previous studies have reported considerable variation for earliness-related traits in bottle gourd. Mishra *et al.* (2019) identified P1 as the earliest line, recording 43.83 days to first male flower anthesis, 45.04 days to first female flower anthesis, and 52.81 days to first fruit harvest. Masud *et al.* (2021) reported wide variation in days to first female flowering (70.75–103.83 days) and

Table 4.3.3: Mean performance (Mean ± SE) of lines and testers in bottle gourd under heat stress conditions

Genotypes	Days to 1st female flower appearance	Node of 1st female flower appearance	Days to 1st edible fruit harvest	Number of fruits per plants	Fruit weight (kg)	Fruit length (cm)	Fruit Diameter (cm)	Yield/Plant (kg)
BG-01	51.29±1.15	18.14±0.74	62.14±1.20	14.14±0.65	1.97±0.07	34.71±0.67	11.59±0.29	32.42±1.21
BG-02	54.93±1.02	16.21±0.40	65.50±1.97	13.64±	1.95±0.68	36.14±0.03	11.99±0.49	28.18±0.29
BG-05	48.86±1.47	21.00±0.97	63.71±0.97	9.29±0.56	1.78±0.02	12.06±0.34	15.96±0.23	15.46±0.98
BG-07	50.50±1.17	20.86±0.70	66.71±1.17	9.50±1.99	2.13±0.04	32.87±0.42	12.24±0.17	21.00±3.75
BG-16	53.07±1.49	22.07±0.66	64.36±1.20	11.29±1.49	1.92±0.03	29.79±0.47	13.15±0.46	21.50±2.97
BG-21	54.00±0.89	17.67±0.52	64.50±1.30	9.71±2.57	2.05±0.31	25.55±2.93	17.37±2.52	17.21±5.21
BG-28	48.93±0.91	20.00±0.82	61.50±0.96	12.14±0.77	2.28±0.07	33.14±0.40	12.23±0.19	23.76±1.48
BG-35	54.36±0.64	21.50±1.30	66.21±0.57	14.50±0.49	1.94±0.05	20.98±0.78	12.61±0.23	27.19±0.97
BG-36	58.93±0.89	20.71±0.50	69.43±0.84	13.43±0.49	1.90±0.03	34.43±0.62	11.46±0.10	26.63±1.14
BG-37	60.50±0.53	19.62±0.72	69.86±0.59	10.95±0.46	1.60±0.06	20.41±0.19	15.38±0.06	26.65±1.05
BG-39	58.50±0.94	17.64±0.65	70.29±0.81	8.40±1.51	1.73±0.23	29.80±3.00	13.01±1.49	16.83±2.96
BG-42	52.14±0.94	19.10±0.67	65.21±0.76	12.71±0.35	2.03±0.04	15.60±0.31	15.52±0.39	24.19±0.81
BG-43	54.50±2.63	18.21±0.96	67.43±2.38	11.71±0.66	1.89±0.07	27.64±1.08	14.35±0.23	24.37±1.44
BG-45	61.64±1.05	18.50±0.25	72.50±0.84	13.86±0.38	1.90±0.01	21.75±0.63	13.74±0.10	26.75±0.72
BG-53	51.50±1.03	19.00±0.91	61.00±1.03	16.50±0.91	1.63±0.05	31.80±0.25	10.80±0.20	28.35±1.19
BG-54	51.79±0.37	14.50±0.50	62.14±0.25	22.00±0.33	1.29±0.04	11.36±0.10	14.35±0.10	27.36±0.64
BG-55	55.36±0.96	15.79±1.29	65.57±0.84	17.43±0.44	1.91±0.03	12.06±0.15	15.91±0.14	29.17±0.87
BG-56	55.93±1.52	25.79±0.80	67.21±1.62	9.32±0.58	1.80±0.03	14.39±0.18	15.34±0.14	17.84±1.11
BG-57	53.93±1.27	21.93±2.02	64.71±1.39	7.38±0.54	1.89±0.08	16.02±1.32	15.94±0.11	13.95±1.05
BG-18	64.57±1.08	33.86±1.11	75.79±0.96	10.29±0.38	2.07±0.03	45.50±0.38	10.49±0.07	21.96±0.82
BG-03	64.79±4.13	23.86±1.22	74.86±5.21	11.14±1.00	1.75±0.16	28.36±2.37	10.95±1.28	20.47±2.04
BG-58	49.86±1.34	14.95±1.51	60.50±0.78	14.14±0.75	1.69±0.01	18.52±1.43	15.94±0.53	20.57±1.31
Mean	54.99	20.04	66.42	12.43	1.87	25.13	13.65	23.26
SE (±)	1.00	0.89	0.91	0.71	0.04	2.01	0.44	1.06
CV (%)	8.54	20.73	6.40	26.94	11.12	37.44	15.00	21.36

days to first harvest (75.58–100.42 days) among different lines. Similarly, Janaranjani *et al.* (2016) observed 46.00–48.67 days to first female flower appearance and 56.80–66.23 days to first harvest, which was closely aligned with the findings of the present study.

Fruit length and diameter are key traits determining fruit shape, size, and ultimately yield. The highest mean fruit length was recorded in BG-18 (45.50 cm), followed by BG-02 (36.14), BG-01 (34.71), BG-36 (34.43), and BG-28 (33.14), while the shortest fruits were observed in BG-54 (11.36 cm), BG-55 (12.06 cm), BG-05 (12.06 cm), BG-56 (14.39 cm), and BG-42 (15.60 cm). For fruit diameter, BG-21 showed the largest diameter (17.37 cm), followed by BG-05 (15.96), BG-57 (15.94), BG-55 (15.91), and BG-42 (15.52), whereas BG-18 had the smallest diameter (10.49 cm), followed by BG-53 (10.80), BG-36 (11.46), BG-01 (11.59), and BG-02 (11.99). Janaranjani *et al.* (2016) reported that fruit length for lines ranged from 30.90 cm to 53.73 cm and fruit width ranged from 22.87 cm to 40.40 cm. These ranges were consistent with previous reports by Khot *et al.* (2021), Hadiya *et al.* (2020), and Yadav *et al.* (2025), confirmed substantial genetic variability for fruit size traits in bottle gourd.

The number of fruits per plant is one of the most determining traits for fruit yield. Among the examined lines, BG-54 (22) possessed the highest number of fruits per plant followed by BG-55 (17.43), BG-53 (16.50), BG-35 (14.50), and BG-01 (14.14). In contrast, BG-57 (7.38) had the lowest number of fruits per plant, followed by BG-39 (8.40), BG-05 (9.29), BG-56 (9.32), and BG-07 (9.5). Whereas, fruit weight is another important factor that contributed to the fruit yield. The highest mean performance for average fruit weight was recorded in BG-28 (2.28), followed by BG-07 (2.3), BG-18 (2.07), BG-21 (2.05), and BG-42 (2.03), while the lowest fruit weight was recorded in BG-54 (1.29), followed by BG-37 (1.60), BG-53 (1.63), BG-39 (1.73), and BG-05 (1.78). The highest mean performance for fruit yield per plant was recorded in BG-01 (32.42), followed by BG-55 (29.17), BG-53 (28.35), BG-02 (28.18), and BG-54 (27.36) while lowest mean performance was estimated in BG-57 (13.95), followed by lines BG-05 (15.46), BG-39 (16.83), BG-21 (17.21), and BG-56 (17.84). Masud *et al.* (2021) reported that among lines, the number of fruits per plant ranged from 3.00 to 7.08, fruit weight from 1.25 to 2.00 kg, and yield per plant from 4.3 to 11.5 kg, while testers recorded 3.03–4.92 fruits per plant, 1.42–1.57 kg fruit weight, and 4.7–7.4 kg yield per plant. Similar ranges for these traits were also reported by Janaranjani *et al.* (2016), Raut and Mishra (2015), and Hadiya *et al.* (2020), supported the present observations.

4.3.4 Pooled ranking of mean performance and GCA effects

The potential of a variety as a parent for hybridization or commercial hybrid development can be assessed through its mean performance and combining ability (Suthanthirapandian, 1986). While mean performance reflects the individual strength of a parent, F_1 performance indicates hybrid vigor, and GCA and SCA effects reveal the genetic compatibility and potential of parental lines to produce superior hybrids. GCA and mean performance are interrelated and should be considered together when selecting parents. Crosses with high F_1 means, appropriate SCA, and at least one parent with high GCA are more likely to concentrate desirable genes and improve target traits (Kenga *et al.*, 2004).

The estimates of GCA effects and mean performance of the examined lines and testers revealed that the identification of good general combiners was inconsistent across various criteria. Different traits recognized different lines and testers as good general combiners, which may be contradictory. To provide an overall assessment, a ranking approach was used. Genotypes were ranked based on both mean performance and GCA effects, with the most desirable traits receiving the lowest ranks (good combiners) and the least desirable traits receiving the highest ranks (poor combiners). This combined ranking allowed the selection of the most promising parents, and the results are presented in Table 4.3.4.

Pooled rankings based on mean performance and GCA for seven key traits including earliness (days to first female flower and first edible fruit harvest), fruit characters (length and diameter), and yield components (number of fruits per plant, fruit weight, and yield per plant) revealed substantial variability among parental genotypes, reflecting their differential breeding potential. Among the lines, BG-01 was possessed as the best parent, securing rank 1 (Total Rank = 99). It's exhibited a consistently favorable rank for earliness, fruit length, number of fruits, and yield per plant. It also estimated desirable good GCA effects, indicating its strong additive gene contribution. Moreover, following that, BG-16 and BG-21, which possessed rank 2 (total rank 106) and rank 3 (total rank 107), also showed good performance of many traits with good GCA effects for yield and its components, identified as reliable and good general combiners.

Beside this, lines BG-42 (rank total 132), BG-36 (rank total 136), BG-54 (137), BG-55 (BG-148), and BG-53 (BG-149) occupied in the intermediate positions. These genotypes

Table 4.3.4: Comparative performance of parental lines and tester based on pooled mean and GCA ranking

Parents	Days to 1st female flower appearance		Days to 1st edible fruit harvest		Number of fruits per plants		Fruit weight (kg)		Fruit length (cm)		Fruit Diameter (cm)		Yield/Plant (kg)		Total Rank	Rank
	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA		
Lines																
BG-01	4	11	3	14	5	1	6	8	3	1	17	16	1	9	99	1
BG-02	13	7	10	6	7	2	7	19	2	4	16	13	4	5	115	5
BG-05	1	14	5	16	18	3	16	12	18	20	2	6	19	12	162	14
BG-07	3	5	13	1	16	4	2	2	6	10	14	10	15	14	115	6
BG-16	8	3	6	4	12	5	9	1	9	3	11	18	14	3	106	2
BG-18	20	17	20	19	14	20	3	17	1	8	20	19	13	20	211	20
BG-21	10	9	7	5	15	6	4	4	11	12	1	5	17	1	107	3
BG-28	2	10	2	11	10	7	1	10	5	2	15	17	12	13	117	7
BG-35	11	4	12	2	4	8	8	5	13	9	13	14	6	4	113	4
BG-36	17	2	16	3	8	9	11	7	4	6	18	15	9	11	136	9
BG-37	18	18	17	10	13	10	19	14	14	14	6	7	8	19	187	17
BG-39	16	15	18	17	19	11	17	13	8	5	12	11	18	18	198	19
BG-42	7	12	9	9	9	12	5	9	16	18	5	4	11	6	132	8
BG-43	12	19	15	18	11	13	14	11	10	13	9	9	10	8	172	15
BG-45	19	13	19	13	6	14	12	3	12	11	10	12	7	10	161	13
BG-53	5	6	1	12	3	15	18	16	7	7	19	20	3	17	149	12
BG-54	6	1	4	7	1	16	20	20	20	19	8	8	5	2	137	10
BG-55	14	8	11	8	2	17	10	18	19	16	4	3	2	16	148	11
BG-56	15	16	14	15	17	18	15	6	17	17	7	1	16	7	181	16
BG-57	9	20	8	20	20	19	13	15	15	15	3	2	20	15	194	18
Testers																
BG-03	2	2	2	2	2	1	1	1	1	1	2	2	1	1	21	
BG-58	1	1	1	1	1	2	2	2	2	2	1	1	2	2	21	

demonstrated either good earliness, fruit characters, or yield attributes but they performed inconsistently in all the studied traits. Among them, BG-55 and BG-53 estimated higher individual rank on fruit yield and yield components and BG-42 possessed good rank for both mean and GCA. These lines were useful for trait-specific breeding potential, especially for yield components. Higher total rank values indicated inferior overall performance. The lines including BG-18 (rank 20), BG-39 (rank 19), BG-57 (rank 18), and BG-37 (rank 17) performed very poorly in terms of mean performance and GCA effects, indicated that very limited potential in hybridization programs aimed at yield and earliness improvement.

Both testers, BG-03 and BG-58, recorded the lowest total rank values (Total Rank = 21), proved their excellent mean performance and strong GCA effects across all traits. Their consistent superiority confirmed their suitability as good testers for evaluating combining ability and for developing high-performing hybrids.

4.3.5 Parent selection

The primary goal of any breeding program is to improve yield. Combining ability has become an important tool in plant breeding, as it provides insight into the genetic potential of parents and the inheritance of key traits (Kumar *et al.*, 2018). Identifying good general combiners is essential for developing hybrids with superior yield and quality. Crosses between parents with high GCA effects were more likely to produce progeny with high trait values, facilitating easier selection and successful hybrid development (Janaranjani *et al.*, 2016). GCA estimates of lines and testers serve as practical tools for selecting superior parents in cross-pollinated crops (Hallauer *et al.*, 1988; Longin *et al.*, 2013).

Based on mean performance, genetic variability, and relationships among yield components, earliness (days to first flowering and harvest), fruit traits, and yield components were identified as key criteria for parent and trait selection in GCA studies using Line × Tester analysis. The magnitude and nature of combining ability effects guided the identification of superior parents for use in hybridization programs.

The results of the ranking of GCA values and mean performances of lines and testers, six parents were selected for further breeding through full diallel crossings. According to the ranking of lines, the lowest pooled ranks were possessed in the lines BG-01, BG-16, and BG-21 among all the studied lines and were identified as good general combiners.

Moreover, the BG-42, BG-55, and BG-53 exhibited intermediate pooled ranked among the lines, which were considered as average general combiners. The combinations of the selected genotypes BG-01 were good combiners for earliness, fruit length, and fruit yield, while BG-42 (round) and BG-55 (round shape) were exceptionally good in fruit diameter in terms of mean performance and GCA effects. Vekariya *et al.* (2019) suggested that the crosses between two high general combiners were not always the best. Bhalala and Acharya (2019) exhibited high SCA effect manifestations of crosses involving both parents have high GCA effects, which might be attributed to sizable additive × additive gene action. The good × poor combinations, besides expressing the favorable additive effect of the parent, manifested some complementary gene interaction effects with a higher SCA. Therefore, six parents were judiciously selected for diallel crossings.





Tester 1: BG-03



Tester 2: BG-58

Plate 4.3.1: Fruit morphotypes of twenty lines (A) and two testers (B-C) used under Line × Tester experiment

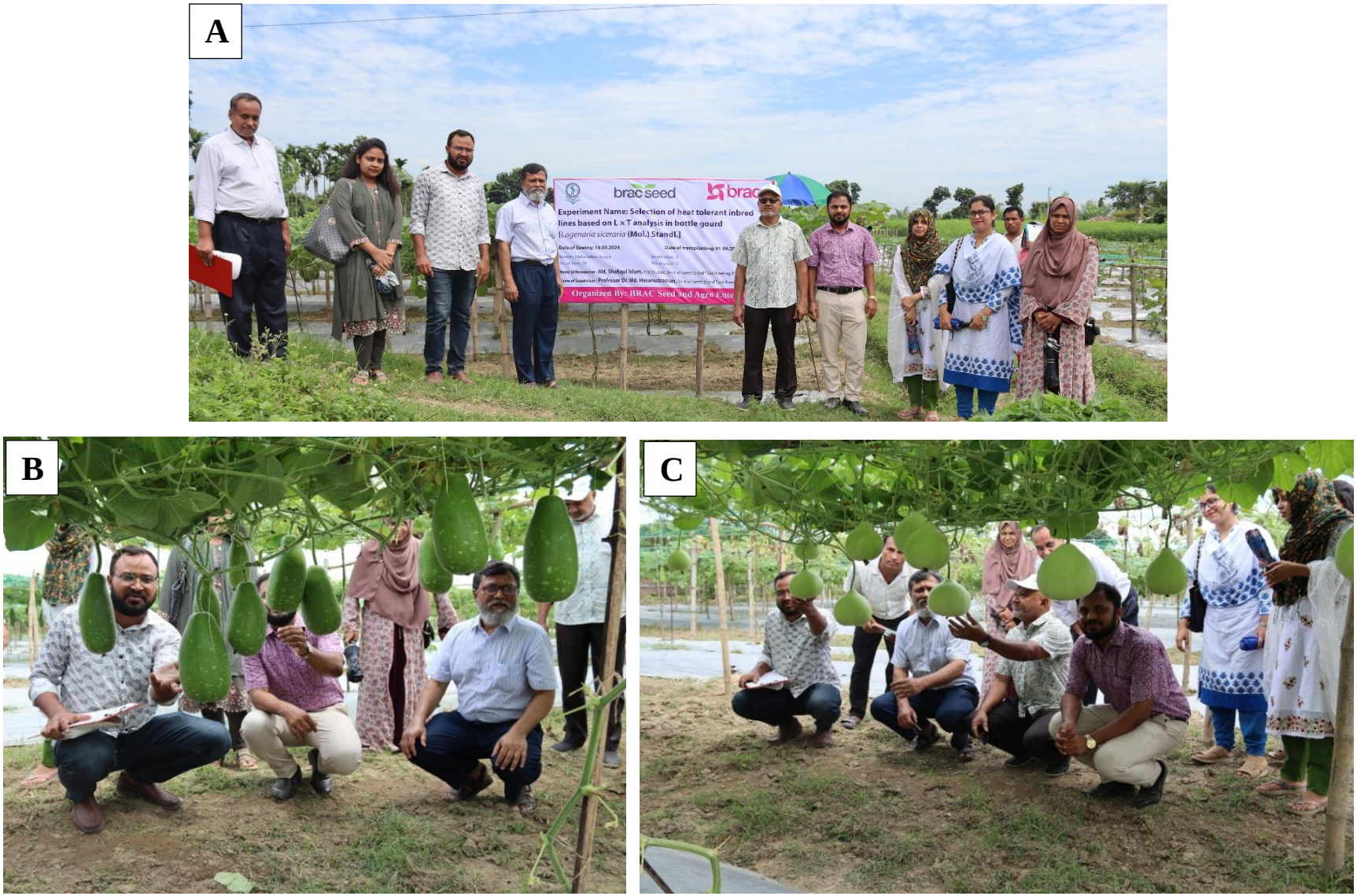


Plate 4.3.2: Photographs (A-C) showing experimental field visited by supervisory committee

4.4 Experiment-IV: Combining Ability and Heterosis Analysis of Selected Heat-Tolerant Genotypes in Bottle Gourd

Among the various methods available for quantitative genetic analysis, diallel cross analysis is considered one of the most efficient approaches for identifying superior parents for hybridization. Combining ability analysis (Griffing, 1956 a) provides insight into the genetic architecture of traits and helps estimate the breeding potential of parental lines through key genetic parameters. This approach enables breeders to evaluate genetic relationships and select superior parents and cross combinations. Diallel analysis partitions genetic effects into general combining ability (GCA), which reflects the average performance of a parent across hybrid combinations, and specific combining ability (SCA), which denotes the performance of a particular cross over the parental mean. Significant GCA and SCA effects indicate the relative importance of additive and non-additive gene actions and support informed parental selection (Kearsey and Pooni, 1996).

The diallel method also facilitates the accumulation of desirable genes from diverse genotypes (Dabholkar, 1992). In the present study, genetic analysis was carried out using variance component analysis and combining ability analysis (Griffing, 1956 a), where GCA variance primarily represents additive gene action and SCA variance represents non-additive effects, including dominance and epistasis. Observed cases of negative heterosis may be attributed to non-allelic interactions or the presence of a higher frequency of decreasing alleles, while the absence of significant heterosis in certain crosses may result from the cancellation of positive and negative effects or non-unidirectional dominance. For effective heterosis breeding, the selection of parents should be based on both combining ability and mean performance. Accordingly, the following section presents the results of combining ability and heterosis estimates for six parental lines and their 30 hybrids, including reciprocals, evaluated in bottle gourd under heat stress conditions.

4.4.1 Analysis of Combining Ability of the Selected Parents

General combining ability (GCA) refers to the average performance of a parent across hybrid combinations, whereas specific combining ability (SCA) reflects the deviation of particular crosses from their expected performance based on parental averages (Sprague and Tatum, 1942). Genetically, GCA is largely governed by additive gene effects, while SCA is primarily influenced by non-additive effects such as dominance and epistasis (Rojas and Sprague, 1952). Additive effects are more predictable and heritable across

generations, making them highly valuable to plant breeders for developing stable and improved lines. Diallel cross analysis is widely employed to estimate both GCA and SCA, providing essential information for identifying superior parental genotypes and evaluating their genetic potential. Based on GCA estimates, parents may be classified as good combiners with high GCA effects, poor combiners with low GCA effects, or average combiners with moderate GCA effects falling between these extremes.

4.4.1.1 Analysis of variance (ANOVA) for combining ability

The analysis of variance (ANOVA) revealed significant differences among genotypes for all the studied phenology, yield-related and quality traits, indicating the presence of substantial genetic variability (Table 4.4.1). The diallel analysis showed that mean squares due to general combining ability (GCA), specific combining ability (SCA), and reciprocal effects were significant for most of the traits studied. GCA variances were significant for all traits except dry matter, whereas SCA and reciprocal variances were highly significant for all traits, indicating the involvement of both additive and non-additive gene actions. Highly significant GCA and SCA variances for all eleven traits suggested that both additive and dominance gene effects played an important role in the inheritance of these characters. In several traits, including days to first female flower appearance, node number of first female flower, days to first edible fruit harvest, number of fruits per plant, yield per plant and total soluble solids (TSS), reciprocal effects were higher than SCA, indicating the greater influence of non-additive gene action. Shinde *et al.* (2016) reported that both additive and non-additive gene actions were involved in the inheritance of bottle gourd traits. Similarly, Ray *et al.* (2015), Vegad *et al.* (2011) and Dubey and Maurya (2006) observed highly significant GCA and SCA mean squares for most traits, which was in close agreement with the results of the present study.

The magnitudes of GCA and SCA effects further reflect the relative contribution of additive and non-additive gene actions in trait inheritance (Griffing, 1956b; Kornegay & Temple, 1986). A larger GCA:SCA ratio indicates predominance of additive gene effects, whereas a lower ratio suggests the influence of dominance or epistatic interactions. The ratios of general combining ability (GCA) were greater than those of specific combining ability (SCA) and reciprocal combining ability for most of the characters (Table 4.4.1), indicating the predominance of additive genetic variance in the inheritance of these traits.

Table 4.4.1: Mean square values of analysis of variance (ANOVA) for eleven earliness, yield and quality traits of bottle gourd of a 6 × 6 full Diallel cross

Source of Variation	Degrees of freedom	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble Solids (^{0}Brix)	Dry matter (mg/100g)	Ascorbic Acid (mg/100 g)
Replication	2	1.28	1.44	4.01	3.07	0.02	0.004	0.14	0.72	0.005	0.03*	0.15
Crosses/Gen	35	27.81**	15.64**	37.44**	102.48**	12.99**	0.10**	16.57**	57.28**	1.92**	1.42**	1.51**
GCA	5	31.24**	11.23**	47.84**	196.99**	23.61**	0.05*	8.98*	42.66**	1.12*	0.63	0.97*
SCA	15	4.22**	2.56**	3.80**	8.51**	1.11**	0.03**	4.11**	12.98**	0.52**	0.49**	0.34**
Reciprocal	15	7.00**	5.86**	9.37**	5.53**	1.13**	0.03**	5.93**	20.69**	0.61**	0.40**	0.51**
Error	70	0.70	0.25	0.50	0.81	0.07	0.0012	0.06	0.17	0.002	0.002	0.003
Variance Components												
δ_g^2		2.26	0.73	3.68	15.73	1.88	0.002	0.38	1.68	0.05	0.01	0.05
δ_s^2		2.04	1.34	1.92	4.47	0.60	0.017	2.36	7.44	0.30	0.29	0.20
δ_r^2		3.15	2.81	4.44	2.36	0.53	0.013	2.93	10.26	0.30	0.20	0.26
δ_g^2: δ_s^2		1.11	0.54	1.92	3.52	3.12	0.13	0.16	0.23	0.17	0.04	0.27
δ_g^2: δ_r^2		1.39	3.85	1.21	0.15	0.28	6.19	7.74	6.13	6.06	15.73	4.77
GCA: SCA		7.41	4.39	12.59	23.15	21.33	2.79	2.17	3.29	2.12	3.33	2.85
RCA: GCA		0.22	0.52	0.20	0.03	0.05	0.32	0.66	0.48	1.17	0.82	1.50

Here, *p≤0.05 and **p≤0.01 level of probability.

This suggested that additive gene action was mainly responsible for the expression of these characters. The estimated GCA:SCA ratios were greater than unity for all the traits, indicating a significant role of additive gene action and suggesting that pure-line breeding would be effective for the improvement of these traits. Similar high GCA:SCA ratios for protein, dry matter, ascorbic acid, total soluble solids (TSS), and yield per plant in bottle gourd were also reported by Jha *et al.* (2016).

Additive and non-additive genetic components were assessed using the ratio δg^2: δs^2, where δg^2 represents additive variance and δs^2 represents non-additive variance (Iftekheddaula, 2003). In the present study, traits such as node number of first female flower appearance, fruit weight, number of fruits per plant, yield per plant, total soluble solids (°Brix), dry matter, and ascorbic acid content exhibited δg^2: δs^2 ratios less than one, indicating that dominant gene action predominantly governed their expression. Conversely, traits including days to first female flower appearance, days to first edible fruit harvest, fruit length, and fruit diameter showed ratios greater than one, demonstrating the predominance of additive gene action. These findings were supported by earlier research reports by various authors. Adarsh *et al.* (2015) observed δg^2: δs^2 ratios less than one for all traits studied, suggesting dominance variance as a major component in trait expression. Similarly, Ray *et al.* (2015) reported GCA:SCA ratios below unity for most traits, indicated a predominance of non-additive genetic variance, except for fruit length, which was consistent trend with the present results.

4.4.1.2 Estimation of general combining ability (GCA) effects for parents

Selection of suitable parents is vital in any hybridization program, and combining ability analysis helps identify promising parents and crosses by revealing the type and magnitude of gene action controlling key traits. The GCA effects of the six parental inbred lines (Table 4.4.2) allowed classification of parents as good, average, or poor combiners based on the direction, magnitude, and significance of their effects. Parents with desirable significant GCA effects were rated as good combiners, those with non-significant effects as average, and those with significant undesirable effects as poor. These results provide useful guidance for selecting parents and formulating effective breeding strategies, as shown in Table 4.4.2 and Figure 4.4.1 and fruit morphotypes are depicted in Plate 4.4.1. Character-wise interpretations of GCA effects are summarized below.

Earliness traits

Earliness in bottle gourd was determined by days to first female flower appearance, node number to first female flower, and days to first edible fruit harvest. Negative GCA effects are desirab for these traits, as earlier reported by Dey *et al.* (2012), as they indicate the ability of parents to transmit earliness to their progeny.

For days to first female flower appearance, negative GCA effects were considered desirable because they indicate a parental ability to transmit earliness to its progeny. The general combining ability (GCA) effects for days to first female flower appearance ranged from -2.87 in BG-01 to 1.59 in BG-21. Parents BG-01 (-2.87) and BG-16 (-0.64) showed significant negative GCA effects and were identified as good general combiners for earliness, whereas BG-21 (1.59) and BG-42 (1.17) exhibited high positive and undesirable effects and were considered as poor general combiners. Besides this, for node number at first female flower appearance, GCA estimates ranged from -1.36 in BG-01 to 1.31 in BG-53. Significantly higher negative GCA values were recorded in BG-01 (-1.36) and BG-16 (-0.89), indicating their superiority for early flowering. In contrast, BG-53 (1.31) and BG-21 (0.42) showed significant positive and undesirable effects. For days to first edible fruit harvest, GCA values varied from -3.12 in BG-01 to 2.30 in BG-55. The parents BG-01 (-3.12) and BG-16 (-1.53) showed strong negative and desirable GCA effects, marking them as good general combiners for early fruit maturity under heat stress during summer season. Researchers also recorded consistent findings with the current results by Adarsh *et al.* (2015); GCA ranged from -0.61 to 0.61 for node number to first pistillate flower anthesis, -2.79 to 2.93 for days to first pistillate flower anthesis, and -3.51 to 3.14 for days to first fruit harvest. Similarly, Keshari and Singh (2024) recorded GCA ranges from -1.54 (Pusa Sandesh) to 1.81 (NDBG-104) for days to first pistillate flower anthesis and -1.97 (Pusa Sandesh) to 1.81 (NDBG-104) for days to first fruit harvest, supporting the present observations. Parmar and Pathak (2018) recorded GCA ranges of -1.38 (Punjab Komal) to 1.92 (Punjab Long) for days to first female flowering, -0.15 (PBOG-7) to 0.20 (PSPL) for the node of the first female flower, and -0.68 (PBOG-7) to 0.52 (Pusa Naveen) for days to first fruit harvest, which were closely aligned with the present study.Similar findings for earliness of these traits were also reported by Masud *et al.* (2021) during winter, Rahaman *et al.* (2025) during monsoon, and Keshari and Singh (2024) during the summer season.

Table 4.4.2: Estimation of general combining ability (GCA) effects in a 6 × 6 diallel cross for earliness, yield and quality traits of bottle gourd

Parents	Days to 1st female flower appearance	Node at first female appearance	Days to edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01	-2.87**	-1.36**	-3.12**	4.19**	-1.08**	-0.01	-0.07	-0.13	-0.20**	0.37**	-0.26**
	45.78	13.67	56.89	33.38	10.77	1.64	8.79	14.04	3.05	4.82	8.09
BG-16	-0.64**	-0.89**	-1.53**	-0.74**	-0.02	-0.07**	0.48**	0.62**	-0.44**	-0.25**	-0.45**
	47.94	15.00	57.55	21.69	13.51	1.56	9.17	14.40	3.10	3.72	8.29
BG-21	1.59**	0.42**	1.30**	2.52**	-0.85**	0.03**	-0.26**	-0.46**	-0.13**	0.04**	0.18**
	54.00	17.33	64.75	29.52	11.90	1.73	7.11	12.24	2.95	3.69	8.30
BG-42	1.17**	0.17	0.94**	-4.05**	1.59**	-0.01	-0.98**	-1.68**	0.31**	-0.04**	0.13**
	54.44	18.33	65.00	15.58	15.82	1.40	6.22	9.28	4.30	4.16	9.15
BG-53	0.07	1.31**	0.10	3.48**	-1.45**	0.11**	1.40**	2.92**	0.21**	-0.24**	0.16**
	48.94	20.00	59.78	26.33	9.78	1.56	8.11	12.90	3.00	3.66	9.50
BG-55	0.69**	0.36**	2.30**	-5.40**	1.82**	-0.06**	-0.58**	-1.27**	0.25**	0.11**	0.24**
	52.61	16.00	65.83	14.21	17.14	1.45	8.22	13.33	3.68	3.66	8.85
SE (Gi)	0.22	0.13	0.19	0.24	0.07	0.01	0.06	0.11	0.012	0.013	0.015
SED (Gi-Gj)	0.34	0.20	0.29	0.37	0.11	0.01	0.10	0.17	0.019	0.020	0.023
CD (Gi) 5 %	0.440	0.263	0.370	0.473	0.141	0.018	0.127	0.214	0.025	0.026	0.029
CD (Gi) 1 %	0.584	0.349	0.491	0.628	0.187	0.024	0.169	0.284	0.033	0.034	0.038

Here, * P<0.05, and ** P<0.01 level of probability and the Lower row of each parent is mean value.

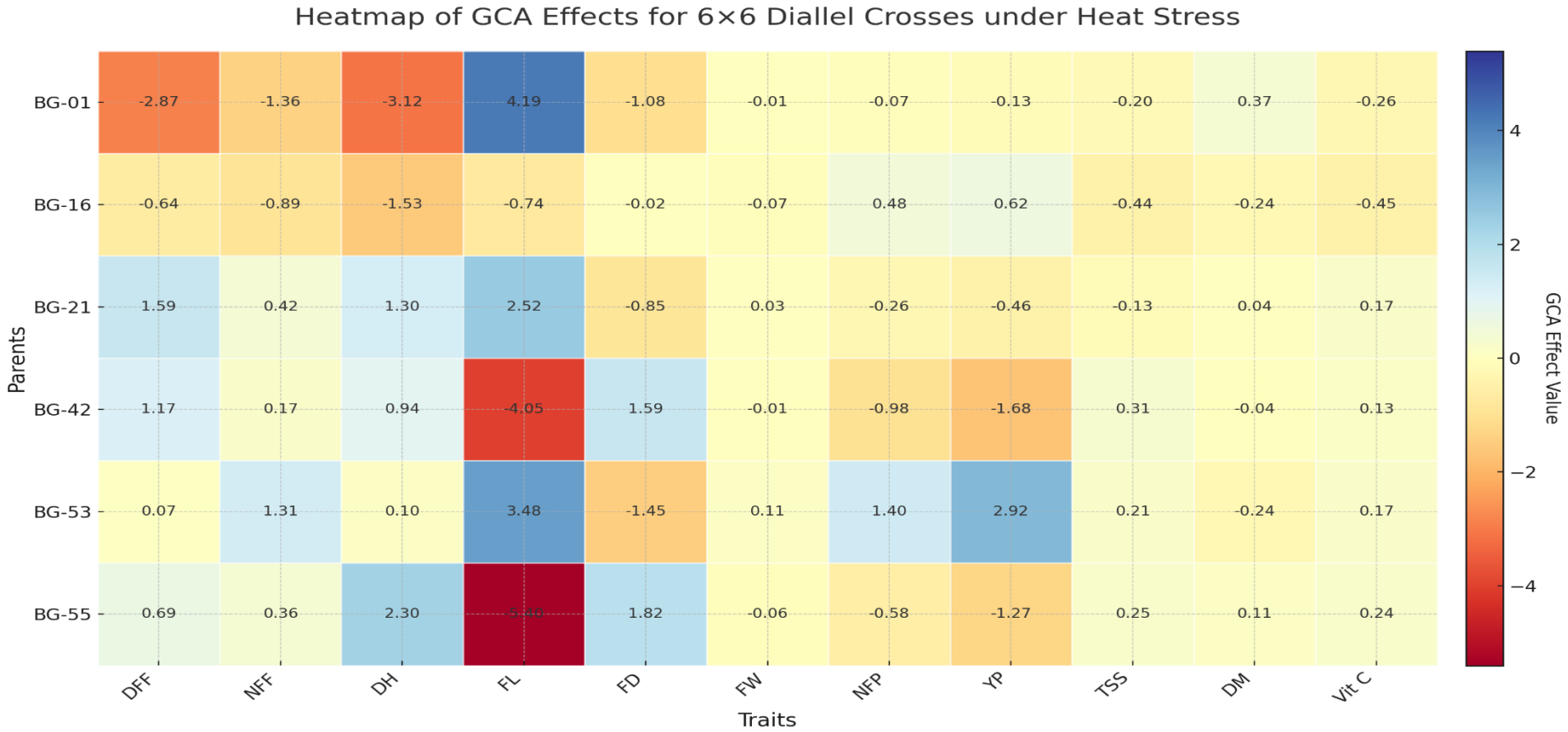


Figure 4.4.1: Heatmap of General combing ability (GCA) effects of bottle gourd parents under heat stress conditions

Note: DFF-Days to first female flower appearance, NFF-Node at which first female flower appearance, DH-Days to first edible fruit harvest, FL-Fruit length, FD-Fruit diameter, FW-Fruit weight (kg), NFP-Number of fruits per plant, YPP-Yield per plant (kg), TSS-Total soluble solids, DM-Dry matter content (mg/100g), VITC-Ascorbic acid content (mg/100 g)

Based on phenological traits on earliness, BG-01 and BG-16 consistently demonstrated desirable negative GCA effects across all earliness traits of days to first female flower appearance, node number of first female flower appearance, and days to first edible fruit harvest and thus could be considered superior parents for developing early-maturing hybrids. Negative GCA effects were considered desirable for earliness in all three maturity traits like node of first female flower, days to first female flower appearance, and days to first edible fruit harvest, as also earlier noted by Dey *et al.* (2012). Significant negative GCA effects desirable for earliness in bottle gourd were also reported by Singh *et al.* (2023), Quamruzzaman *et al.* (2020), and Janaranjani *et al.* (2016). While BG-21, BG-55, and BG-42 displayed significant positive and undesirable GCA effects and were identified as poor general combiners. Whereas, parent BG-53 showed non-significant GCA values and was categorized as an average general combiner for earliness traits in bottle gourd. Parmar and Pathak (2018) identified that parents Punjab Komal showed desirable negative GCA effects for days to first female flowering (-1.38) and days to first fruit harvest, while PBOG-7 was a good combiner for early node of first female flower (-0.15), which was consistent with the present findings. Similar findings were also recorded by Harika *et al.* (2012) and Adarsh *et al.* (2015) for earliness of the said three key traits.

Fruit size (fruit length and diameter)

Considerable variability was observed for fruit morphological traits among the studied parents. The general combining ability (GCA) effects for fruit length varied from -5.40 (BG-55) to 4.19 (BG-01). Among the parents BG-01 (4.19), BG-53 (3.48), and BG-21 (2.52) exhibited significantly positive GCA effects, indicating their suitability as good general combiners for developing longer fruits. Among them, BG-01 recorded the highest positive and significant GCA effect, confirming its superiority for improving fruit length. The positive direction of GCA effects suggested an increased transmission of additive genes governing increased fruit length, making these parents desirable in hybridization programs.

For fruit diameter, the GCA effects ranged from -1.45 (BG-53) to 1.82 (BG-55). Parents BG-55 (1.82) and BG-42 (1.59) displayed strong and significant positive GCA effects, indicating their potential contribution to enhancing fruit diameter. Conversely, BG-53 (-1.45), BG-01 (-1.08), and BG-21 (-0.85) recorded significant negative GCA effects, categorizing them as poor general combiners for this trait. BG-16 showed non-significant

GCA effects, suggesting an average combining ability during heat stress conditions in summer season of Bangaldesh.

These results of fruit traits for fruit length and fruit diameter responses suggested a clear inverse relationship between fruit length and fruit diameter among the studied parents. Genotypes producing longer fruits generally tended to have thinner fruits, whereas those with greater fruit diameter often produced relatively shorter fruits. This contrasting pattern of trait expression was in line with earlier reports. Mahawar *et al.* (2021) observed wide and opposing GCA effects for fruit length (–6.82 to 3.78) and fruit diameter (–1.83 to 2.11). Similar ranges were reported by Rahaman *et al.* (2025) for fruit length (–1.94 to 0.78) and fruit diameter (–0.24 to 0.39) in bottle gourd. Likewise, Vegad *et al.* (2011) documented contrasting GCA effects for fruit length and diameter, further supporting the present findings. These findings indicated that parents with strong general combining ability for fruit length often exhibit weaker combining ability for fruit diameter.

Yield and key yield-contributing traits

The yield and major yield-contributing traits exhibited significant variation among the investigated parents, as demonstrated by their general combining ability (GCA) effects.

Fruit weight (kg)

The GCA effects for fruit weight ranged from -0.07 (BG-16) to 0.11 (BG-53). Among the six parents, BG-53 (0.11) and BG-21 (0.03) exhibited significant positive GCA effects, indicating their ability to transmit favorable alleles for improving fruit weight. These parents were therefore identified as good general combiners for this trait. While BG-16 (-0.07) and BG-55 (-0.06) possessed significant negative GCA effects and were designated as poor general combiners. Keshari and Singh (2024) exhibited GCA effects for average fruit weight ranged from -123.23 (Pusa Samridhi) to 150.33 (Kashi Kirti) and classified Kashi Kirti as an excellent general combiner due to its highly significant positive effect. Similarly, Rahaman *et al.* (2025) reported significant GCA effects for fruit weight ranging from -0.10 (HAJARI) to 0.04 (BG717), which aligns with the findings of the present study. Shinde *et al.* (2016) reported fruit weight ranged from -0.057 (Pusa Naveen) to 0.062 (Bhagirathi) and identified parents Bhagirathi (0.062), Pusa Summer Prolific Long (0.27), and Samart (0.20) as good general combiners.

Number of fruits per plant

The GCA effects for the number of fruits per plant ranged from -0.98 (BG-42) to 1.40 (BG-53). Among the examined parents, BG-53 (1.40) and BG-21 (0.58) recorded strong positive and significant GCA effects and were identified as good general combiners, contributing to an increased number of fruits per plant. In contrast, BG-42 (-0.98), BG-55 (-0.58), and BG-01 (-0.26) showed significant negative GCA effects, indicating their unfavorable contribution to this trait and classified them as poor general combiners. The parent BG-01 (0.07) with a non-significant effect was categorized as an average general combiner. Keshari and Singh (2024) reported that GCA effects for number of fruits per plant ranged from –0.54 (NDBG-104) to 0.59 (Pusa Samridhi), with Narendra Rashmi (0.49) and Pant Lauki-4 (0.23) showing significant positive contributions, which supports the results of the present study. Similarly, Parmar and Pathok (2018) observed GCA values ranging from –0.94 (Pusa Naveen) to 0.65 (Punjab Komal), indicating comparable variability. Rahaman *et al.* (2025) also reported significant GCA effects for number of fruits per plant, varying from –0.34 (BG-722) to 0.68 (BG-714), which was closely agrees with the findings of this investigation.

Yield per plant (kg)

The general combining ability (GCA) effects for yield per plant ranged from -1.68 (BG-42) to 2.92 (BG-53). Among the studied parents, BG-53 (2.92) and BG-16 (0.62) showed strong positive and significant desirable GCA effects, identified them as good general combiners for yield and important contributors of favorable genes toward enhancing fruit yield. Three parents, BG-42 (–1.68), BG-55 (–1.27), and BG-21 (–0.46), recorded significant negative GCA effects, contributing to reduced yield levels, and were thereby classified as poor general combiners for fruit yield per plant. The remaining parent, BG-01 (-0.12), exhibited non-significant GCA effects and was therefore considered an average general combiner. Keshari and Singh (2024) demonstrated that yield per vine showed GCA effects from -0.44 (Pusa Samridhi) to 0.49 (Kashi Kirti), with Pant Lauki-4 (0.37), Pant Lauki-3 (0.27), and NDBG-104 (0.10) identified as the best general combiners, which support the findings of the present study. Parmar and Pathok (2018) reported GCA for yield per plant ranged from -0.36 (PBOG-7) to 0.28 (Pusa Naveen), which supported the findings of the present investigation for fruit yield per plant. Shinde *et al.* (2016) reported that the GCA effect for fruit yield per plant ranged from -3.29 (PBOG-89) to 3.23

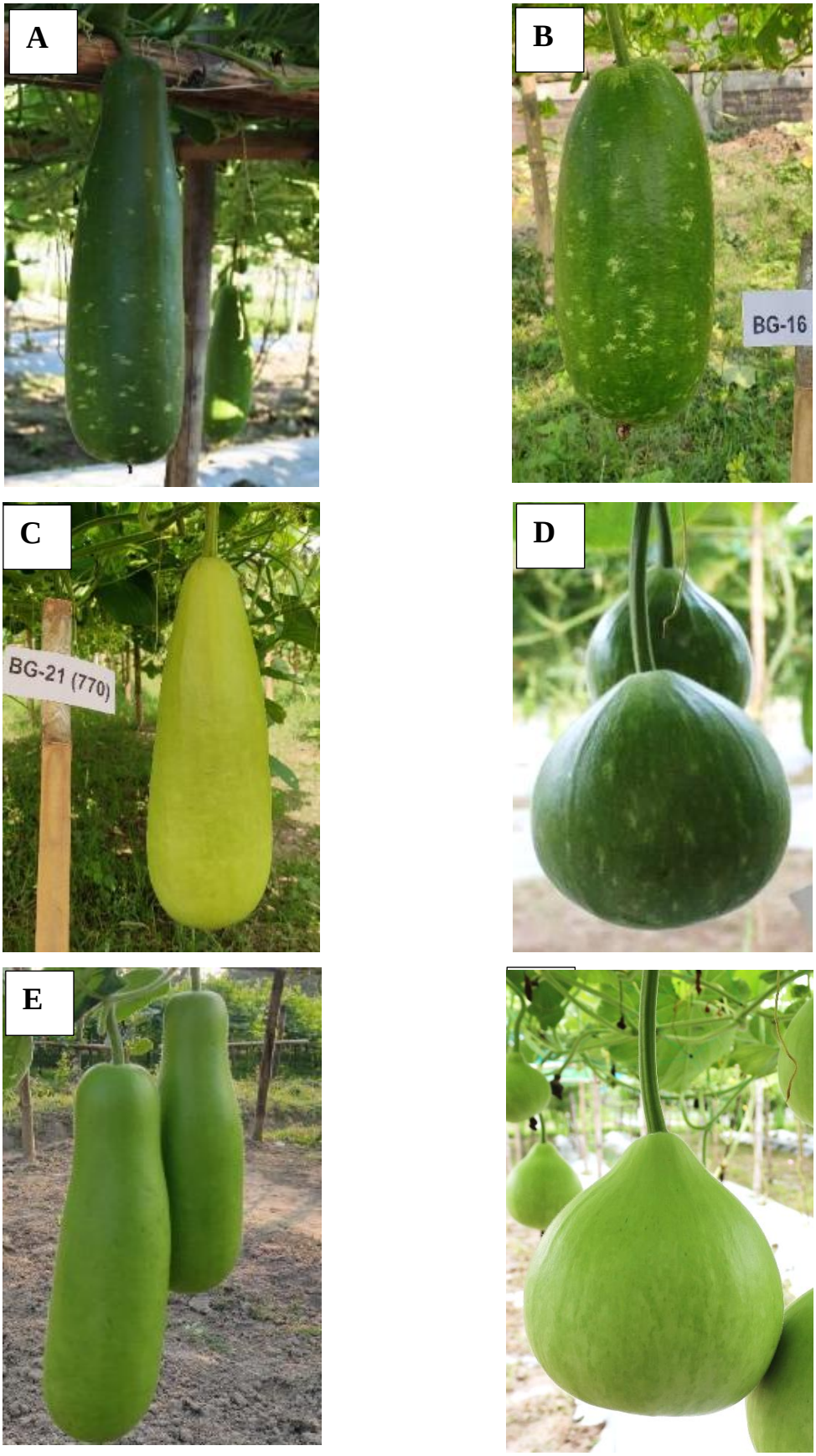


Plate 4.4.1 Fruit morphotypes of six parents (A-F) used in 6 × 6 diallel crosses

(Bhagirathi), and Samrat (1.65), DBG 5 (2.34), and Bhagirathi (3.23) exhibited good general combiners, which identical with the present investigation. Rahaman *et al.* (2025) reported significant GCA effects for yield per plant from -1.40 (HAJARII) to 1.21 (BG-714), which was closely aligned with the findings of the present study.

The evaluation of the six parents revealed distinct differences in their contribution to key yield components. Parent BG-53 consistently performed as best general combiner, expressing significant positive GCA effects for both fruit weight (0.11) and number of fruits per plant (1.40), indicating strong potential for enhancing yield. BG-21 also showed positive GCA effects for both traits, though with lower magnitudes than BG-53, suggesting its moderate contribution toward yield improvement. In contrast, BG-42, BG-55, and BG-01 recorded negative effects for fruit number, and BG-16 showed a negative effect for fruit weight, indicating their poor contribution to yield improvement. The result showed that parents having good GCA effects for yield also had good GCA effects for one or more yield components. The combined influence of fruit weight and fruit number underscored BG-53 was the most suitable parent for developing high-yielding hybrids.

Rahaman *et al.* (2025) reported that BG714 was considered a superior general combiner among the parents for enhancing the fruits (0.68), yield (1.21), and harvest duration (2.42) and was suggested for selecting parents in hybridization in bottle gourd, which was similar to the present findings. Keshari and Singh (2024) reported that the number of fruits per plant and average fruit weight were the major contributors to yield. These findings emphasize that both fruit weight and number of fruits per plant play pivotal roles in yield improvement, which was identical with findings of the present study. Parmar and Pathok (2018) reported PBOG-8 as a good general combiner for fruit weight (27.92) and number of fruits per plant (0.66), and PSPL for marketable yield per plant (0.32), which was consistent with the present results. Similarly, Shinde *et al.* (2016) identified DBG-5, Bhagirathi, and NDBG-129 as good general combiners for yield and yield-contributing traits, where high and significant GCA effects were also associated with superior per se performance.

Quality parameters

The parents included in the study exhibited varied degrees of general combining ability (GCA) for examined key quality traits of total soluble solids (°Brix), dry matter content (%), and ascorbic acid (Vitamin C) content.

Total soluble solids (°Brix)

The general combining ability (GCA) effects for total soluble solids (TSS) ranged from -0.44 (BG-16) to 0.31 (BG-42). The highest positive and significant GCA effect was observed in BG-42 (0.31), followed by BG-55 (0.25) and BG-53 (0.21), identifying these as good general combiners for TSS. In contrast, BG-16 (-0.44) recorded the lowest significant negative effect, followed by BG-01 (-0.20) and BG-21 (-0.13), categorized them as poor general combiners.

Dry matter content (%)

GCA effects for dry matter content varied from -0.25 (BG-16) to 0.37 (BG-01). Among the parents, BG-01 (0.37), BG-55 (0.11), and BG-21 (0.04) showed positive and significant GCA effects and were classified as good general combiners. Three parents, BG-16 (-0.25), BG-53 (-0.24), and BG-42 (-0.04), recorded significant negative effects and were designated poor general combiners.

Ascorbic acid (Vitamin C) content

The GCA effects for ascorbic acid content ranged from -0.45 (BG-16) to 0.24 (BG-55). The parent BG-55 (0.24) showed the highest significant positive GCA effect, making it the best general combiner for ascorbic acid (vitamin C) content, followed by BG-21 (0.18), BG-53 (0.16), and BG-42 (0.13). Conversely, BG-16 (-0.45) and BG-01 (-0.26) exhibited significant negative GCA effects and were categorized as poor general combiners.

None of the parents exhibited consistently high and significant positive GCA effects across all three quality traits, with the exception of BG-55, which demonstrated superior performance specifically in ascorbic acid (vitamin C) content. Parents BG-53 and BG-42 exhibited significant positive general combining ability for total soluble solids and ascorbic acid but demonstrated negative GCA effects on dry matter content. The parent BG-01 recorded the strongest GCA effects for dry matter content and significant negative effects for TSS and ascorbic acid content. These results indicate that no single parent was a universal combiner for all quality traits, reflecting trait-specific gene action. High positive or negative GCA estimates indicate substantial deviation of parental means from the general cross mean, while lower GCA values imply minimal divergence under the heat stress condition in the summer season.

Sriom and Yadav (2021) observed GCA effects ranged from -0.21 to 0.12 for TSS, -0.12 to 0.50 for ascorbic acid, and -0.29 to 0.17 for dry matter content. They also concluded that no parent consistently performed well across all quality traits, which supports trait-specific combining ability with the present findings. Similarly, Bhatt *et al.* (2023) reported parental mean performance ranged from 3.05 to 3.05–6.13% for dry matter, 6.6 to 8.9 mg/100 g for ascorbic acid, and 3.57–5.12 °Brix for TSS. Their GCA analysis identified P2, P3, P4, and P8 as good general combiners for dry matter; P2 and P8 for ascorbic acid; and P1, P2, P4, and P6 for TSS. These findings reinforce that combining ability varies across traits and that no single parent excels in all quality attributes, consistent with the present study. Saryam *et al.* (2024) reported a wide range of GCA effects for TSS (-0.224 to 0.168) and ascorbic acid (-0.684 to 1.446) and identified JBG-4 and JBG-2 as strong general combiners for TSS, with JBG-4 also showing the highest positive effect for ascorbic acid (vitamin C) content. Utilization of combining ability analysis proved to be an efficient approach for identifying superior parents for crossing, either to exploit heterosis or to accumulate favorable genes (Sprague and Tatum, 1942). Parents exhibited high GCA effects for specific characters generally showed good per se performance, as also reported by Shinde *et al.* (2016).

4.4.1.3 Estimation of Specific Combining Ability (SCA) Effects of the Crosses

Specific combining ability (SCA) effects reflect the contribution of non-additive gene action and help identify superior cross-specific hybrid combinations. High SCA effects may occur even in crosses involving poor general combiners, highlighting their potential value in hybrid breeding. Negative SCA effects were desirable for earliness traits, while positive effects were preferred for yield and its components (Dey *et al.*, 2012). The observed variation in SCA effects indicates the involvement of both additive and non-additive gene interactions. Detailed SCA estimates and mean performances of the crosses are presented in Table 4.4.3 and Table 4.4.4.

Earliness traits

Negative significant Specific combining ability (SCA) effects were considered desirable for the selection of earliness in specific crosses. In this study, negative SCA effects were preferred for traits related to flowering and maturity, particularly days to male and female flower appearance, node number of first female flower, and days to first edible harvest, as these indicated earlier expression of the traits (Dey *et al.*, 2012, Ray *et al.* 2015).

Among the fifteen crosses evaluated, five exhibited significant negative specific combining ability (SCA) effects for days to first female flower appearance, indicating their suitability as good specific combiners for earliness. The cross BG-01 × BG-21 showed the most desirable effect (-2.10), followed by BG-21 × BG-55 (-1.99), BG-16 × BG-42 (-1.63), BG-21 × BG-42 (-1.12), and BG-01 × BG-53 (-0.11). These combinations involved good × good, good × poor, good × poor, good × poor, and good × average combiners for days to first female flower appearance, which was consistent with the findings of Keshari and Singh (2024).

The presence of significant negative SCA effects for this trait suggested the predominance of non-additive gene action governing earliness of female flowering. For the node number of first female flower appearance, five crosses demonstrated significant and desirable negative SCA effects. The best specific combiner was BG-21 × BG-53 (-1.78), followed by BG-16 × BG-42 (-0.83), BG-21 × BG-55 (-0.83), BG-16 × BG-53 (-0.81), and BG-01 × BG-16 (-0.64). These crosses involved poor × average, good × poor, poor × poor, good × poor, and poor × poor combinations. These results were further confirmed the importance of non-additive genetic effects in the expression of earliness-related traits.

Similarly, for days to first edible fruit harvest, five crosses showed significant negative and desirable SCA effects and were identified as superior specific combiners. The cross BG-01 × BG-21 recorded the highest negative effect (-2.17), followed by BG-21 × BG-42 (-1.73), BG-16 × BG-55 (-1.57), BG-16 × BG-42 (-1.40), and BG-01 × BG-53 (-1.08), indicating the involvement of non-additive gene action in determining early harvest. These crosses involved good × poor, poor × poor, good × poor, good × poor, and good × average combinations. Similar results were also estimated by Vegad *et al.* (2011) and Keshari and Singh (2024) for days to first fruit harvest. In contrast, three crosses, namely BG-16 × BG-21 (2.47), BG-42 × BG-53 (1.27), and BG-01 × BG-55 (0.86), exhibited significant positive and undesirable SCA effects for days to first edible harvest, suggesting delayed maturity. This indicated that additive gene action may also play a role in certain cross combinations.

The results of earliness demonstrated that non-additive gene action predominated in the inheritance of earliness related traits, suggesting that exploitation of heterosis through hybrid breeding would be an effective strategy for developing early-maturing bottle gourd hybrids. All the promising crosses involved the parental combinations of good × good,

good × poor, and/or poor × poor combinations. Vegad *et al.* (2011) reported that several good × poor parental combinations, including Pusa Naveen × NDBG (Round)-2 (fruit length), NDBG (Round)-2 × NDBG-104 (fruit weight), PBOG-90 × NDBG (Round)-2 (days to first female flower), and Pusa Naveen × NDBG-104 (node of first male flower), produced superior crosses with potential for transgressive and stable segregants. In addition, good × good combinations such as ABG-1 × Bhagirathi and JBOGL-01-6 × Bhagirathi showed high breeding value and were suggested for further exploitation, supporting the effectiveness of both good × good and good × poor crosses in genetic improvement.

Parmar and Pathak (2018) reported that Gutka Long × PBOG-8 showed significant negative SCA for days to first female flowering, while Punjab Komal × Pusa Naveen, Punjab Komal × PBOG-8, and PSPL × PBOG-8 exhibited significant negative SCA for the node of the first female flower. These results support the importance of non-additive gene action in bottle gourd. Shinde *et al.* (2016) reported that 21, 17, and 19 crosses among forty-five exhibited significant and desirable negative SCA effects for days to first female flower appearance, node number of first female flower, and days to first harvest, respectively, indicating enhanced earliness. Notable superior crosses included Samrat × Pusa Summer Prolific Long, Samrat × NDBG 619, Samrat × NDBG 129, and Pusa Summer Prolific Long × Pusa Samrudhi. Similar results have also been reported by Bhaiya and Yadav (2022) and Jayanth *et al.* (2019). These findings were consistent with the present study and confirm the predominance of non-additive gene action in controlling earliness traits in bottle gourd.

Fruit size (fruit length and diameter)

For fruit length, four crosses out of fifteen exhibited significant and positive specific combining ability (SCA) effects and were identified as good specific combiners for increasing this trait. The cross BG-16 × BG-53 showed the highest positive SCA effect (4.24), followed by BG-01 × BG-53 (1.73), BG-01 × BG-21 (1.36), and BG-53 × BG-55 (1.08). These crosses involved poor × good, good × good, good × good, and good × poor parental general combinations. These crosses were considered promising for improving fruit length, suggested the predominance of non-additive gene action in the expression of this trait.

Table 4.4.3: Estimation of specific combining ability (SCA) effects in a 6 × 6 diallel cross for earliness, yield and quality traits of bottle gourd

Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	-0.38	-0.64*	0.41	-1.47**	0.14	0.09*	-1.34**	-1.62**	0.15**	-0.27**	-0.57**
BG-01 × BG-21	-2.10**	1.06**	-2.17**	1.36*	0.20	-0.18**	1.02**	0.53*	0.36**	-0.26**	0.54**
BG-01 × BG-42	1.13*	-0.36	0.17	0.68	-0.04	-0.06**	-0.79**	-1.56**	0.07*	0.50**	-0.01
BG-01 × BG-53	-1.11*	1.17**	-1.08*	1.73**	0.42*	0.15**	0.41**	1.58**	-0.50**	-0.30**	-0.22**
BG-01 × BG-55	0.80	-0.39	0.86*	-1.21*	-1.07**	-0.05*	-1.13**	-1.48**	-0.17**	0.53**	0.23**
BG-16 × BG-21	1.90**	1.75**	2.47**	0.13	0.38*	0.03	-1.51**	-2.24**	0.34**	0.14**	0.05
BG-16 × BG-42	-1.63**	-0.83**	-1.40**	0.05	-0.13	0.05*	0.15	0.97**	-0.92**	0.06*	0.09**
BG-16 × BG-53	0.66	-0.81**	0.77	4.24**	-1.19**	-0.06**	2.21**	4.32**	-0.16**	-0.09**	0.34**
BG-16 × BG-55	0.08	0.97**	-1.57**	-0.03	-0.16	-0.19**	-0.61**	-2.83**	-0.05	0.23**	-0.52**
BG-21 × BG-42	-1.12*	0.53	-1.73**	0.44	-1.33**	-0.03	-1.52**	-2.68**	-0.34**	0.76**	-0.42**
BG-21 × BG-53	2.35**	-1.78**	0.22	-1.21*	0.45**	0.01	1.57**	2.20**	-0.29**	0.07*	-0.18**
BG-21 × BG-55	-1.99**	-0.83**	0.37	0.89	-0.72**	0.11**	-0.09	0.78**	0.07*	-0.04	0.63**
BG-42 × BG-53	-0.61	-0.53	1.27**	0.88	0.33*	0.13**	-0.44**	-0.21	1.13**	-0.46**	-0.19**
BG-42 × BG-55	-0.02	0.42	-0.14	0.36	1.12**	0.10**	1.52**	2.59**	-0.26**	-0.82**	0.21**
BG-53 × BG-55	-0.25	1.78**	0.55	1.09*	-0.09	0.06**	-1.97**	-3.19**	0.58**	0.92**	-0.33**
SE (Sij)	0.503	0.300	0.423	0.541	0.161	0.021	0.145	0.244	0.028	0.030	0.033
SED (Sij-Sik)	0.765	0.456	0.643	0.822	0.245	0.032	0.221	0.371	0.043	0.045	0.050
SED (Sij-Skl)	0.684	0.408	0.575	0.735	0.219	0.028	0.197	0.332	0.038	0.040	0.045
CD 5%	1.004	0.599	0.844	1.079	0.321	0.041	0.290	0.487	0.056	0.059	0.066
CD 1%	1.333	0.795	1.121	1.433	0.426	0.055	0.384	0.646	0.074	0.078	0.088

Here, * P<0.05, and ** P<0.01, level of probability.

Table 4.4.4: Mean performances (mean ± SE) of the crosses for earliness, yield components and quality traits in bottle gourd under heat stress

Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	46.14±0.77	13.00±0.58	57.00±0.66	27.61±0.33	10.83±0.07	1.30±0.05	3.61±0.06	5.67±0.30	3.38±0.02	4.60±0.12	6.81±0.02
BG-01 × BG-21	45.06±0.31	15.33±0.33	55.72±0.63	37.00±0.25	11.60±0.31	1.59±0.02	10.56±0.15	17.00±0.38	4.30±0.06	5.16±0.04	9.37±0.09
BG-01 × BG-42	49.67±0.33	15.33±0.33	58.58±0.74	29.83±0.79	13.45±0.30	1.56±0.06	5.50±0.10	9.02±0.35	3.62±0.07	5.45±0.03	7.71±0.06
BG-01 × BG-53	47.44±0.49	17.67±0.33	56.72±0.83	34.00±0.33	10.46±0.04	1.72±0.05	7.33±0.35	12.43±0.27	2.33±0.03	3.55±0.03	7.74±0.04
BG-01 × BG-55	47.50±0.17	16.33±0.88	60.89±0.40	25.50±0.48	13.20±0.19	1.55±0.05	6.74±0.39	10.90±0.61	2.90±0.06	5.99±0.06	8.84±0.03
BG-16 × BG-21	50.89±0.11	17.00±0.58	59.83±0.25	26.84±0.34	13.10±0.09	1.73±0.02	8.17±0.38	14.04±0.38	3.82±0.04	4.58±0.06	8.73±0.06
BG-16 × BG-42	49.78±0.28	14.00±0.00	59.67±0.76	22.69±0.16	13.77±0.34	1.52±0.02	6.56±0.15	10.93±0.53	2.43±0.03	3.35±0.03	8.07±0.07
BG-16 × BG-53	48.11±0.97	14.67±0.33	60.78±0.72	31.04±0.11	11.32±0.21	1.60±0.04	8.87±0.16	14.83±0.26	2.75±0.03	3.67±0.04	8.46±0.03
BG-16 × BG-55	50.44±0.43	18.33±0.33	61.67±0.42	21.37±0.57	15.01±0.18	1.36±0.03	6.06±0.15	7.95±0.06	2.85±0.03	4.25±0.03	6.51±0.03
BG-21 × BG-42	48.32±1.42	18.00±0.00	59.60±0.31	25.65±0.25	11.39±0.22	1.72±0.03	5.06±0.20	8.17±0.27	3.90±0.06	5.30±0.11	8.53±0.09
BG-21 × BG-53	57.83±1.21	17.00±0.58	66.61±2.17	28.78±0.20	10.01±0.34	1.75±0.01	9.89±0.40	16.88±0.48	3.28±0.04	4.69±0.05	8.79±0.05
BG-21 × BG-55	50.61±1.63	16.00±0.58	67.44±0.91	25.78±0.15	13.15±0.10	1.81±0.02	6.94±0.06	12.67±0.14	3.25±0.03	4.04±0.03	9.25±0.03
BG-42 × BG-53	51.78±0.36	17.33±0.33	64.14±0.22	26.19±0.18	13.12±0.10	1.83±0.01	8.16±0.20	14.04±0.49	5.60±0.06	3.48±0.05	8.21±0.06
BG-42 × BG-55	53.33±0.00	18.00±0.58	65.89±1.28	17.37±0.20	18.40±0.21	1.62±0.03	4.61±0.15	7.44±0.08	3.28±0.06	3.84±0.03	8.96±0.09
BG-53 × BG -55	53.33±0.88	25.67±0.33	69.33±0.44	23.87±0.45	12.75±0.08	1.66±0.02	3.39±0.06	5.82±0.12	5.55±0.03	5.13±0.12	9.12±0.06

In contrast, the crosses BG-01 × BG-16 (-1.47), BG-01 × BG-55 (-1.21), and BG-21 × BG-53 (-1.21) exhibited significant negative and undesirable SCA effects for fruit length, indicating their poor specific combining ability for this trait. Such negative effects suggested the possible involvement of additive gene action in these particular cross combinations.

For fruit diameter, five crosses out of fifteen showed significant positive SCA effects and were identified as good specific combiners. These crosses were BG-42 × BG-55 (1.12), BG-21 × BG-53 (0.45), BG-01 × BG-53 (0.42), BG-16 × BG-21 (0.38), and BG-42 × BG-53 (0.33). The presence of significant positive SCA effects in these crosses indicated the predominance of non-additive gene action governing fruit diameter. These crosses included good × good, poor × poor, poor × poor, average × poor, and good × poor combinations. Conversely, some crosses exhibited significant negative and undesirable SCA effects for fruit diameter. The crosses BG-21 × BG-42 (-1.33), BG-16 × BG-53 (-1.19), BG-01 × BG-55 (-1.07), and BG-21 × BG-55 (-0.72) showed poor combining ability for this trait, indicated a greater role of additive gene action in these combinations.

These findings suggested that non-additive gene action plays a major role in the inheritance of fruit length and fruit diameter in bottle gourd, highlighted the potential of exploiting heterosis and hybrid breeding strategies for improving these yield-contributing traits. Shinde *et al.* (2016) reported that fourteen crosses exhibited significant positive SCA effects for fruit length, with Samrat × NDBG 619, Samrat × Bhagirathi, Pusa Summer Prolific Long × Bhagirathi, and Pusa Samrudhi × NDBG 129 identified as superior specific combiners, indicating the predominance of non-additive gene action and corroborating the results of the present study. Islam (2017) reported significant positive SCA effects for fruit length in the crosses BG-581 × BG-522, BG-498 × BG-581, BG-657 × BG-581, and BG-582 × BG-489, and for fruit diameter, exhibited highest in BG-498 × BG-582, followed by Hajari × BG-657, Hajari × BG-498, BG-657 × BG-522, and BG-498 × BG-657, indicated the predominance of non-additive gene action and supported the findings of the present study.

Yield and key yield-contributing traits

Fruit weight and number of fruits per plant are major yield contributing traits influencing overall yield. For fruit weight, six out of fifteen crosses exhibited significant positive specific combining ability (SCA) effects. The cross BG-01 × BG-53 showed the highest

positive SCA effect (0.15), followed by BG-42 × BG-53 (0.13), BG-21 × BG-55 (0.11), BG-42 × BG-55 (0.10), BG-53 × BG-55 (0.06), and BG-16 × BG-42 (0.05). These crosses were possessed in combination with the parents of average × good, poor × good, poor × poor, poor × poor, good × poor, and poor × poor combinations, respectively. These results indicated the predominance of non-additive gene action in the inheritance of fruit weight.

For the number of fruits per plant, wide variation was observed among the crosses for specific combining ability (SCA) effects. Five crosses exhibited significant positive SCA effects, with BG-16 × BG-53 (2.21) being the best specific combiner, followed by BG-21 × BG-53 (1.57), BG-42 × BG-55 (1.52), BG-01 × BG-21 (1.02), and BG-01 × BG-53 (0.41) for number of fruits per plant. These crosses included good × good, poor × good, poor × poor, average × poor, and average × good parental combinations. In contrast, several crosses showed significant negative SCA effects, including BG-53 × BG-55 (-1.97), BG-21 × BG-42 (-1.52), BG-01 × BG-16 (-1.34), BG-01 × BG-55 (-1.13), and BG-16 × BG-21 (-0.51), indicated poor specific combining ability for this trait.

For fruit yield per plant, specific combining ability (SCA) effects varied widely from -3.19 (BG-53 × BG-55) to 4.32 (BG-16 × BG-53). Seven crosses recorded significant positive SCA effects. The cross BG-16 × BG-53 (4.32) was identified as the best specific combiner, followed by BG-42 × BG-55 (2.59), BG-21 × BG-53 (2.20), BG-01 × BG-53 (1.58), BG-16 × BG-42 (0.97), BG-21 × BG-55 (0.78), and BG-01 × BG-21 (0.53). These crosses possessed good × good, poor × poor, poor × good, average × good, good × poor, poor × poor, and average × poor combinations. Conversely, seven crosses exhibited significant negative SCA effects, namely BG-53 × BG-55 (-3.19), BG-16 × BG-55 (-2.83), BG-21 × BG-42 (-2.68), BG-16 × BG-21 (-2.24), BG-01 × BG-16 (-1.62), BG-01 × BG-42 (-1.56), and BG-01 × BG-55 (-1.48), indicating reduced yield potential in these combinations.

The predominance of positive SCA effects in superior crosses indicated that a major role of non-additive gene action in controlling fruit weight, fruit number, and fruit yield per plant confirmed the potential of heterosis breeding for yield improvement in bottle gourd. The presence of strong specific (SCA) effects, especially when combined with good GCA parents, suggests the potential for obtaining valuable transgressive segregants in future generations (Jinks and Jones, 1958). The above results (Table 4.4.3) indicate that hybrids with superior performance might arise even from parents with poor GCA effects. This

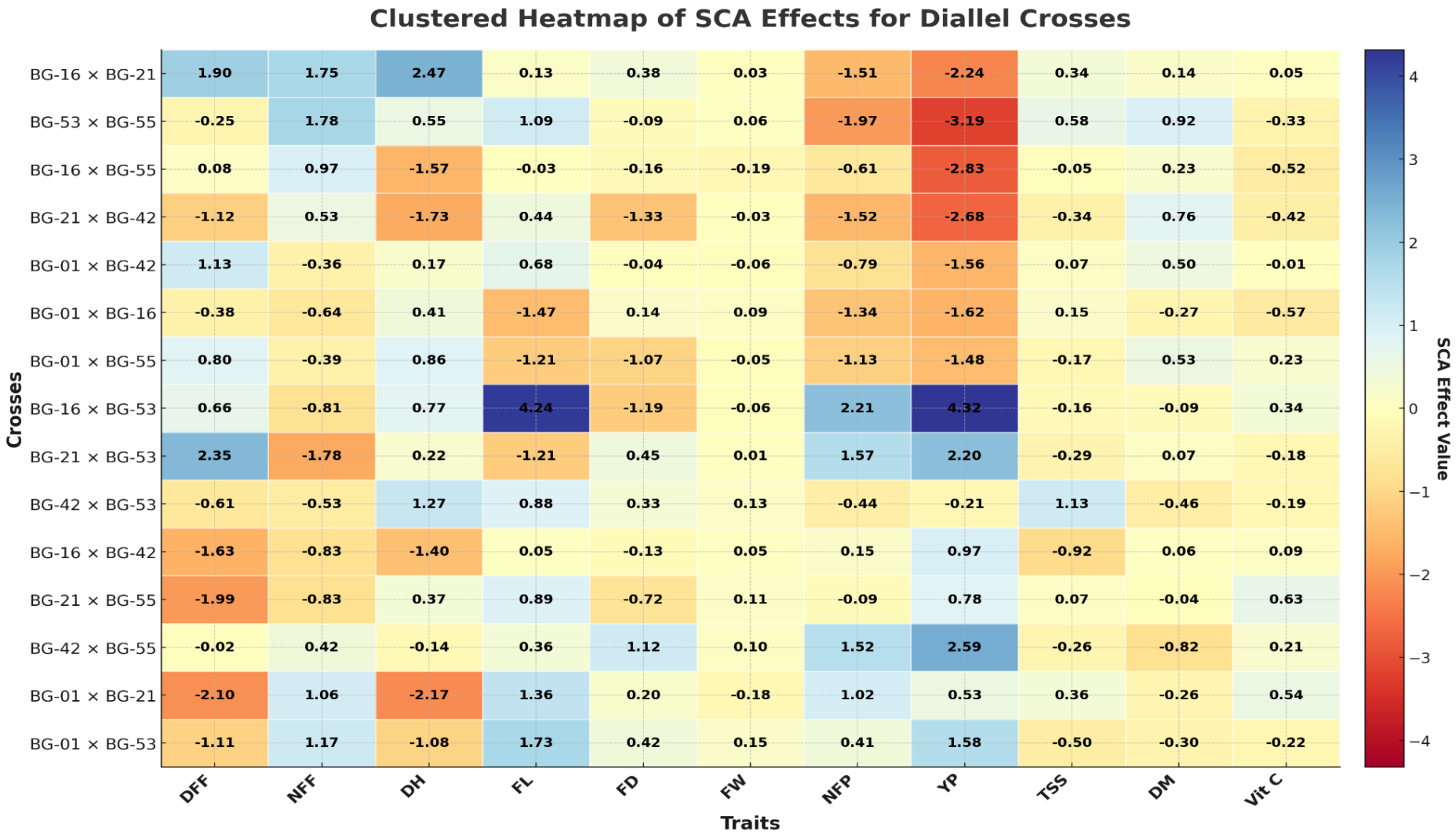


Figure 4.4.2. Clustered Heatmap for Specific Combining ability effects for 6x6 Diallel crosses in bottle gourd

underscores that the best crosses don't solely arise from high GCA parent crosses. These combinations were good × good, good × poor, poor × poor, good × average, and poor × average combinations. Promising crosses, driven by additive gene action and fixable, hold promise for heterosis breeding and segregant selection in advanced generations. Similar and consistent findings had also been documented by Bhatt *et al.* (2023). Islam (2017) reported significant positive SCA effects for fruit weight in crosses like Hajari × BG-581, BG-498 × BG-582, and Hajari × BG-522, indicating both additive and non-additive gene action. For number of fruits per plant and yield per plant, significant SCA effects were observed in both directions, highlighting combined gene effects. Superior crosses such as Hajari × BG-581 and BG-498 × BG-581 were identified for yield traits, supported the present study. Keshari and Singh (2024) reported significant positive SCA effects for fruit weight, number of fruits per plant, and yield, highlighted the role of non-additive gene action. Superior crosses included Kashi Kirti × Kashi Kiran, Pant Lauki-4 × Kashi Kirti, and Pusa Samridhi × Kashi Kiran. Similarly, Parmar and Pathak (2018) identified crosses such as PBOG-7 × PBOG-8 and PSPL × Gutka Long as superior specific combiners for fruit weight and number of fruits, supported the present findings.

Quality parameters

For total soluble solids (TSS, °Brix), six out of fifteen crosses exhibited significant and positive SCA effects and were identified as good specific combiners. Among the crosses, BG-42 × BG-53 (1.13) showed the highest positive SCA effect followed by BG-53 × BG-55 (0.58), BG-01 × BG-21 (0.36), BG-16 × BG-21 (0.34), BG-01 × BG-16 (0.15), BG-21 × BG-55 (0.07), and BG-01 × BG-42 (0.07), indicating the predominance of non-additive gene action for this trait. These crosses included good × good, good × good, poor × poor, poor × poor, poor × good, and poor × good, respectively. In contrast, several crosses exhibited significant negative SCA effects, notably BG-16 × BG-42 (-0.92), BG-01 × BG-53 (-0.50), BG-21 × BG-42 (-0.34), BG-21 × BG-53 (−0.29), and BG-42 × BG-55 (-0.26), suggested poor specific combining ability in these combinations.

For dry matter content (mg/100 g), eight crosses showed significant positive SCA effects, whereas six crosses recorded significant negative effects. The best specific combiner was BG-53 × BG-55 (0.92), followed by BG-21 × BG-42 (0.76), BG-01 × BG-55 (0.53), and BG-01 × BG-42 (0.50). These crosses included poor × good, good × poor, good × good, and good × poor combinations, respectively. Conversely, crosses such as BG-42 × BG-55

(-0.82), BG-42 × BG-53 (-0.46), BG-01 × BG-53 (-0.30), BG-01 × BG-16 (-0.27), and BG-01 × BG-21 (-0.26) exhibited significant negative SCA effects, indicating the involvement of additive gene action in these combinations.

For ascorbic acid (vitamin C) content, significant SCA effects were observed in both positive and negative directions, indicating complex genetic control. Among the evaluated fifteen crosses six showed significant positive SCA effects, with BG-21 × BG-55 (0.63) being the best specific combiner, followed by BG-01 × BG-21 (0.54), BG-16 × BG-53 (0.34), BG-01 × BG-55 (0.23), and BG-42 × BG-55 (0.21). These promising crosses involved good × good, poor × good, poor × good, poor × good, and good × good, respectively. On the other hand, several crosses exhibited significant negative SCA effects, including BG-01 × BG-16 (-0.57), BG-16 × BG-55 (-0.52), BG-21 × BG-42 (-0.42), BG-53 × BG-55 (-0.33), BG-01 × BG-53 (-0.22), BG-42 × BG-53 (-0.19), and BG-21 × BG-53 (−0.18), which were considered undesirable for improving vitamin C content.

The results indicated that both additive and non-additive gene actions govern quality traits such as total soluble solids (TSS), dry matter, and ascorbic acid content, suggesting that appropriate exploitation of both heterosis breeding and selection-based approaches could be effective for improving fruit quality in bottle gourd. Saryam *et al.* (2024) reported that both additive and non-additive gene actions govern quality traits such as TSS (%) and ascorbic acid content, which agrees with the findings of the present study. Similarly, Bhatt *et al.* (2023) observed the involvement of additive and non-additive gene actions in the inheritance of TSS, dry matter content, and ascorbic acid, supporting the present investigation. They also reported that strong SCA effects, even from crosses involving poor GCA parents, indicated potential for transgressive segregants and heterosis breeding, emphasized that superior hybrids were not limited to high × high GCA crosses.

4.4.1.4 Estimation of Combining Ability Effects of the Reciprocal Crosses

The reciprocal effects (rij) of fifteen (15) reciprocal crosses and mean performance of the respective crosses for eleven different characters studied are presented in Table 4.4.5 and Table 4.4.6.

Earliness traits

For days to first female flower appearance, four reciprocal crosses exhibited significant and desirable negative effects, indicating their potential for improving earliness. The most

pronounced negative reciprocal effect was observed in BG-42 × BG-21 (-3.17), followed by BG-53 × BG-16 (-1.83), BG-21 × BG-16 (-1.81), and BG-21 × BG-01 (-1.42). In contrast, several crosses showed significant positive and undesirable reciprocal effects, namely BG-55 × BG-21 (3.97), BG-55 × BG-53 (2.97), BG-55 × BG-42 (1.64), and BG-53 × BG-01 (1.50), indicating delayed flowering in these combinations. For node number at which first female flower appearance, seven reciprocal crosses showed significant negative effects, suggesting favorable cytoplasmic or maternal influences on earliness. The best reciprocal effect was observed in BG-16 × BG-53, followed by BG-21 × BG-01 (-2.00), BG-42 × BG-16 (-1.67), BG-16 × BG-01 (-1.33), BG-55 × BG-21 (-1.17), and BG-53 × BG-42 (-0.83). Whereas, only one reciprocal cross, BG-55 × BG-53 (5.00), exhibited a significant positive and undesirable reciprocal effect.

For days to first edible fruit harvest, both significant negative and positive reciprocal effects were recorded. Three crosses, namely BG-21 × BG-16 (-3.71), BG-42 × BG-21 (-2.20), and BG-21 × BG-01 (-1.58), showed desirable negative reciprocal effects and were identified as good reciprocal combinations for early fruit harvest. Conversely, significant positive and undesirable reciprocal effects were observed in BG-55 × BG-53 (5.08), BG-53 × BG-21 (3.69), BG-55 × BG-21 (2.18), and BG-55 × BG-42 (1.50), indicating delayed fruit harvest. These findings suggest that maternal and cytoplasmic effects play an important role in the inheritance of earliness-related traits, and that the direction of crossing should be carefully considered when developing early-harvesting bottle gourd hybrids. Mohsin (2015) reported the similar reciprocal effects for days to first male and female flowering and days to first fruit harvest in pumpkin, and Chowdhury (2021) reported the similar finding for days to first female flowering, days to 50% female flowering, and days to first harvest in tomato.

Fruit size (Fruit length and diameter)

For fruit length, five reciprocal crosses exhibited significant and desirable positive effects, namely BG-42 × BG-21 (2.92), BG-21 × BG-01 (2.83), BG-55 × BG-01 (1.82), BG-55 × BG-21 (1.68), and BG-42 × BG-16 (1.33), indicating favorable maternal or cytoplasmic influences on fruit elongation. In contrast, four reciprocal crosses showed significant negative and undesirable effects, including BG-53 × BG-21 (-2.11), BG-53 × BG-16 (-2.04), BG-53 × BG-01 (-1.50), and BG-55 × BG-53 (-1.41), suggested poor reciprocal performance for fruit length.

Table 4.4.5: Estimation of reciprocal combining ability effects in a 6 × 6 diallel cross of earliness, yield and quality traits of bottle gourd

Reciprocal Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	0.18	-1.33**	-0.06	-0.46	-0.80**	-0.32**	-2.55**	-4.96**	0.52**	0.47**	-0.50**
BG-21 × BG-01	-1.42*	-2.00**	-1.58**	2.83**	0.74**	0.14**	2.78**	5.30**	0.92**	0.74**	0.32**
BG-21 × BG-16	-1.81**	-1.50**	-3.71**	-1.16	1.00**	0.13**	2.36**	4.37**	0.70**	0.37**	0.37**
BG-42 × BG-01	0.38	-0.33	-0.69	2.92**	0.38*	0.03	0.25	0.63*	0.08*	0.35**	-0.74**
BG-42 × BG-16	1.02	-1.67**	0.37	1.33*	-0.27	-0.06*	-0.20	-0.74*	0.13**	-0.70**	-0.28**
BG-42 × BG-21	-3.17**	-0.33	-2.20**	0.64	-0.61**	0.12**	0.72**	1.24**	0.70**	0.27**	0.07
BG-53 × BG-01	1.50*	-0.67	-0.47	-1.50*	-0.03	-0.14**	-1.50**	-3.70**	-0.53**	-0.55**	-0.54**
BG-53 × BG-16	-1.83**	-2.17**	0.14	-2.04**	1.38**	0.02	-2.32**	-4.79**	-0.21**	-0.04	-0.18**
BG-53 × BG-21	3.97**	-0.17	3.69**	-2.11**	-0.74**	-0.01	0.09	0.46	0.14**	0.55**	0.04
BG-53 × BG-42	1.29*	-0.83*	0.54	-0.22	0.05	-0.01	1.08**	1.25**	0.60**	-0.06	-0.48**
BG-55 × BG-01	-0.97	0.50	-0.44	1.82**	0.94**	0.06*	1.43**	2.02**	-0.34**	0.72**	0.04
BG-55 × BG-16	0.47	0.67	1.17*	1.44*	0.78**	0.07**	-0.34*	-0.32	-0.27**	-0.13**	-1.34**
BG-55 × BG-21	0.47	-1.17**	2.18**	1.68**	0.31	0.12**	0.78**	1.87**	-0.30**	-0.34**	-0.38**
BG-55 × BG-42	1.64**	-0.17	1.50**	0.35	1.27**	-0.02	-2.45**	-3.95**	-0.38**	0.32**	-0.21**
BG-55 × BG-53	2.97**	5.00**	5.08**	-1.41*	-0.13	-0.07**	-2.56**	-4.40**	1.15**	0.07*	0.46**
SE (Rij)	0.592	0.353	0.498	0.637	0.190	0.024	0.171	0.287	0.033	0.035	0.039
SED (Rij-Rkl)	0.838	0.500	0.704	0.900	0.268	0.035	0.242	0.406	0.047	0.049	0.055
CD 5%	1.181	0.705	0.993	1.269	0.378	0.049	0.341	0.573	0.066	0.069	0.078
CD 1%	1.568	0.936	1.318	1.686	0.502	0.065	0.453	0.761	0.088	0.092	0.103

Here, * P<0.05, and ** P<0.01, level of probability.

Table 4.4.6: Mean performances (mean ± SE) of the reciprocal crosses for earliness, yield and quality traits in bottle gourd under heat stress

Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	45.78±0.24	15.67±0.33	57.11±0.43	28.53±0.26	12.43±0.50	1.94±0.03	8.71±0.23	15.59±0.60	2.35±0.03	3.67±0.02	7.80±0.03
BG-21 × BG-01	47.89±0.11	19.33±0.67	58.89±0.22	31.33±0.51	10.12±0.10	1.31±0.01	5.00±0.17	6.40±0.02	2.47±0.09	3.68±0.04	8.72±0.04
BG-21 × BG-16	54.50±0.58	20.00±1.15	67.25±1.09	29.16±5.03	11.10±0.39	1.46±0.02	3.44±0.24	5.30±0.24	2.42±0.04	3.85±0.03	7.99±0.04
BG-42 × BG-01	48.92±0.71	16.00±0.00	59.97±0.32	24.00±0.14	12.68±0.38	1.50±0.01	5.00±0.10	7.75±0.29	3.46±0.03	4.76±0.06	9.19±0.05
BG-42 × BG-16	47.73±0.18	17.33±0.67	58.93±0.24	20.03±0.49	14.31±0.13	1.65±0.04	6.94±0.40	12.41±0.61	2.17±0.07	4.75±0.03	8.62±0.04
BG-42 × BG-21	54.67±1.01	18.67±0.33	64.00±0.50	24.37±0.22	12.62±0.04	1.48±0.04	3.61±0.06	5.69±0.07	2.50±0.06	4.76±0.04	8.40±0.05
BG-53 × BG-01	44.44±0.40	19.00±0.00	57.67±0.38	36.99±0.39	10.51±0.20	1.99±0.05	10.33±0.35	19.83±0.50	3.40±0.06	4.65±0.03	8.81±0.06
BG-53 × BG-16	51.78±0.44	19.00±0.58	60.50±0.44	35.11±0.24	8.55±0.00	1.58±0.04	13.50±0.25	24.40±0.44	3.17±0.03	3.75±0.03	8.82±0.06
BG-53 × BG-21	49.89±0.24	17.33±0.33	59.22±0.06	33.00±0.53	11.49±0.18	1.77±0.03	9.72±0.20	15.96±0.37	3.00±0.06	3.60±0.05	8.71±0.06
BG-53 × BG-42	49.20±0.20	19.00±0.58	63.07±0.55	26.63±0.12	13.02±0.11	1.86±0.01	6.00±0.19	11.55±0.49	4.40±0.06	3.60±0.06	9.17±0.09
BG-55 × BG-01	49.44±0.29	15.33±0.33	61.78±0.62	21.86±0.29	11.31±0.18	1.43±0.04	3.89±0.15	6.86±0.06	3.58±0.02	4.56±0.03	8.76±0.04
BG-55 × BG-16	49.50±3.04	17.00±0.58	59.33±1.17	18.48±0.06	13.45±0.89	1.21±0.05	6.72±0.34	8.60±0.61	3.38±0.04	4.50±0.06	9.18±0.04
BG-55 × BG-21	49.67±0.30	18.33±0.88	63.08±0.17	22.43±0.23	12.53±0.24	1.58±0.01	5.39±0.11	8.94±0.18	3.86±0.03	4.71±0.07	10.01±0.06
BG-55 × BG-42	50.06±0.55	18.33±0.33	62.89±0.84	16.67±0.22	15.86±0.18	1.67±0.02	9.50±0.42	15.34±0.74	4.05±0.03	3.20±0.06	9.37±0.09
BG-55 × BG-53	47.39±0.64	15.67±0.33	59.17±0.60	26.68±0.24	13.00±0.24	1.79±0.05	8.50±0.29	14.62±0.17	3.25±0.03	4.99±0.03	8.20±0.06

For fruit diameter, seven reciprocal crosses exhibited significant positive effects and were considered desirable, namely BG-53 × BG-16 (1.38), BG-55 × BG-42 (1.27), BG-21 × BG-16 (1.00), BG-55 × BG-01 (0.94), BG-55 × BG-16 (0.78), BG-21 × BG-01 (0.74), and BG-42 × BG-01 (0.38). These results indicate the importance of maternal effects in improving fruit diameter. Conversely, three reciprocal crosses, BG-16 × BG-01 (-0.80), BG-53 × BG-21 (-0.74), and BG-42 × BG-21 (0.61), exhibited significant negative reciprocal effects and were considered poor combinations for fruit diameter.

The results observed reciprocal effects suggested that maternal and cytoplasmic gene effects significantly influence fruit length and diameter, emphasized the importance of cross direction while designing hybridization programs in bottle gourd. Singh and Singh (2019) also estimated the specific combining ability of the reciprocal crosses, which was consistent with the present research. Mohsin (2015) also reported the identical findings with the current findings for specific combining ability of the reciprocal crosses.

Key yield-contributing traits

Yield in bottle gourd is a complex trait, largely influenced by components such as fruit weight, number of fruits per plant, and ultimately fruit yield per plant. Reciprocal effects play an essential role in understanding maternal and cytoplasmic influences on these traits.
For fruit weight, six reciprocal crosses exhibited significant and desirable positive effects, indicating favorable maternal or cytoplasmic effects. The best reciprocal effect was observed in BG-21 × BG-01 (0.14), followed by BG-21 × BG-16 (0.13), BG-42 × BG-21 (0.12), BG-55 × BG-21 (0.12), BG-55 × BG-16 (0.07), and BG-55 × BG-01 (0.06), suggesting their potential for improving fruit weight. In contrast, some reciprocal crosses showed significant negative and undesirable effects, notably BG-16 × BG-01 (-0.32), BG-53 × BG-01 (-0.14), BG-53 × BG-55 (-0.07), and BG-42 × BG-16 (-0.06), indicating poorer maternal effects for this trait.
For the number of fruits per plant, six reciprocal crosses showed significant positive and desirable effects. The cross BG-21 × BG-01 (2.78) recorded the highest positive reciprocal effect, followed by BG-21 × BG-16 (2.36), BG-55 × BG-21 (1.43), BG-53 × BG-42 (1.08), BG-55 × BG-21 (0.78), and BG-42 × BG-21 (0.72). Conversely, the crosses BG-55 × BG-53 (-2.56), BG-16 × BG-01 (-2.55), BG-55 × BG-42 (-2.45), BG-53 × BG-16 (-2.32), BG-53 × BG-01 (-1.50), and BG-55 × BG-16 (-0.34) exhibited significant negative reciprocal effects, indicated poor performance for this trait.

For fruit yield per plant, six out of fifteen reciprocal crosses showed significant positive effects. The best reciprocal effect was observed in BG-21 × BG-01 (5.30), followed by BG-21 × BG-16 (4.37), BG-55 × BG-01 (2.02), BG-55 × BG-21 (1.87), BG-53 × BG-42 (1.25), BG-42 × BG-21 (1.24), and BG-42 × BG-01 (0.63), indicating their superiority for yield improvement under heat stress conditions. In contrast, crosses such as BG-16 × BG-01 (-4.96), BG-53 × BG-16 (-4.79), BG-53 × BG-55 (-4.40), BG-55 × BG-42 (-3.95), BG-53 × BG-01 (-3.70), and BG-42 × BG-16 (-0.74) showed significant negative reciprocal effects, suggesting poor maternal influence and reduced yield performance. Mohsin (2015) also reported significant specific combining ability effects for reciprocal crosses in pumpkin. Singh and Singh (2019) reported that parents, crosses, and their respective reciprocals differed significantly with their general and specific combining abilities. They also demonstrated that reciprocal crosses indicated that good specific cross combinations were NDBG-208 x NDBG-140 for fruit yield per plant and number of fruits per plant in bottle gourd, which was identical with present findings. These findings demonstrated that reciprocal effects significantly influence major yield components in bottle gourd, especially under heat stress. Several crosses showed strong and desirable maternal effects, indicating that the direction of crossing was crucial in hybrid development, particularly for improving fruit weight, fruit number, and yield per plant.

Quality parameters

For total soluble solids (TSS, °Brix), reciprocal effects were significant in both positive and negative directions, indicating a strong influence of maternal and cytoplasmic factors on this trait. The most desirable reciprocal effect was observed in BG-55 × BG-53 (1.15), followed by BG-21 × BG-01 (0.92), BG-21 × BG-16 (0.70), BG-42 × BG-21 (0.70), BG-53 × BG-42 (0.60), BG-53 × BG-21 (0.14), and BG-42 × BG-16 (0.13). In contrast, undesirable negative reciprocal effects were recorded in BG-53 × BG-01 (-0.53), BG-55 × BG-42 (-0.38), BG-55 × BG-01 (-0.34), BG-55 × BG-21 (-0.30), BG-55 × BG-16 (-0.27), and BG-53 × BG-21 (-0.27), suggesting poor reciprocal performance for TSS in these combinations.

For dry matter content (mg/100 g), several crosses exhibited significant positive reciprocal effects, with BG-21 × BG-01 (0.74) showing the most favorable effect, followed by BG-55 × BG-01 (0.72), BG-16 × BG-01 (0.47), BG-21 × BG-16 (0.37), BG-42 × BG-01 (0.35), BG-55 × BG-42 (0.32), and BG-42 × BG-21 (0.27). These results indicate the



Plate 4.4.2. Fruit morphotypes of six parents and their derived 30 F_1 hybrid fruits

beneficial role of maternal effects in improving dry matter content. Conversely, negative reciprocal effects were observed in BG-42 × BG-16 (-0.70), BG-53 × BG-01 (-0.55), BG-55 × BG-21 (-0.34), and BG-55 × BG-16 (-0.13), reflecting unfavorable reciprocal influences in these crosses.

For ascorbic acid content (mg/100 g), three crosses displayed significant positive and desirable reciprocal effects. The best reciprocal effect was recorded in BG-55 × BG-53 (0.47), followed by BG-21 × BG-16 (0.37) and BG-21 × BG-01 (0.32), suggesting their potential use for improving vitamin C content. In contrast, several crosses exhibited significant negative reciprocal effects, including BG-55 × BG-16 (-1.34), BG-42 × BG-01 (-0.74), BG-53 × BG-01 (-0.54), BG-16 × BG-01 (-0.50), BG-53 × BG-42 (-0.48), BG-55 × BG-21 (-0.38), BG-42 × BG-16 (-0.28), and BG-55 × BG-42 (-0.21), indicating undesirable reciprocal influences on this trait. Mohsin (2015) also reported significant positive and negative specific combining ability for reciprocal crosses in traits of total soluble solids (TSS) in pumpkin. The results further demonstrated that reciprocal and maternal effects significantly influence quality-related traits such as TSS, dry matter, and ascorbic acid in bottle gourd. These findings indicated the importance of the direction of crossing in breeding programs aimed at improving nutritional and quality attributes, particularly under heat stressful environments.

4.4.2 Estimation of heterosis in bottle gourd under heat stress condition

In the present study, heterosis was assessed for earliness, yield, and quality-related traits. Negative heterosis was considered desirable for maturity and earliness parameters, namely node of first female flower appearance, days to first female flowering, and days to first edible harvest, as reduced values indicate early crop maturity. In contrast, positive heterosis was regarded as desirable for yield and yield-contributing traits such as fruit length, fruit diameter, average fruit weight, number of fruits per plant, and yield per plant, since higher values reflect superior hybrid performance. Similarly, positive heterosis was considered desirable for quality traits, including total soluble solids (°Brix), dry matter content, and ascorbic acid content (mg/100 g), as increased values indicated improved nutritional and market quality (Ghuge *et al.* 2016).

4.4.2.1 Heterosis over mid-parent

Heterosis over mid-parent for earliness traits

Heterosis over mid-parent of the crosses and reciprocals crosses are presented in the Table 4.4.7 and 4.4.8 respectively. Superior hybrids for earliness were identified through heterosis estimation in bottle gourd, consistent with earlier findings (Doloi *et al.*, 2018).

For days to first female flower appearance, among the thirty evaluated cross combinations, twelve hybrids exhibited significant mid-parent heterosis with values ranged from -10.88% (BG-21 × BG-42) to 12.36% (BG-21 × BG-53). While, eight crosses expressed significant and desirable negative heterosis, indicating enhanced earliness. These crosses included BG-21×BG-42 (-10.88%), BG-01×BG-21 (-9.69%), BG-21×BG-55 (-5.06%), BG-42×BG-16 (-6.76%), BG-55×BG-21 (-6.83%), BG-53×BG-16 (-6.88%), BG-55×BG-42 (-6.49%), BG-55×BG-53 (-6.67%), and BG-53×BG-01 (-6.15%).

For the node number at first female flower appearance, heterosis ranged from -16.19% (BG-16 × BG-53) to 42.59% (BG-53 × BG-55). Three hybrids showed significant negative and desirable heterosis, such as BG-16×BG-53 (-16.19%), BG-16×BG-42 (-16.00%), and BG-55×BG-53 (-12.96%), indicated their strong potential for early flowering. Regarding days to first edible fruit harvest, heterosis varied from -8.38% (BG-01 × BG-21) to 10.39% (BG-55 × BG-53). Nine hybrids expressed significant desirable negative heterosis, suggesting their suitability for early marketable yield for days to first edible fruit harvest. The most promising crosses included BG-01×BG-21 (-8.38%), BG-21×BG-42 (-8.13%), BG-55×BG-53 (-5.79%), BG-53×BG-21 (-4.88%), BG-55×BG-42 (-3.86%), BG-55×BG-16 (-3.83%), and BG-55×BG-21 (-3.38%), which possessed negatively significant heterosis over mid-parent for days to first edible fruit harvest.

The current findings were consistent with previous studies of several researchers. Ghuge *et al.* (2016) reported significant desirable heterosis for earliness among 28 bottle gourd hybrids, with TC 092372 × VRBG VAR-45 expressing the most negative heterosis (-11.3%) for days to first female flower appearance and -12.4% for days to first harvest. Similarly, Islam (2017) observed heterosis for node number at first female flower ranging from -9.97% to 18.59%, where BG-498 × BG-657 showed the most desirable negative heterosis (-9.97%). For days to 50% female flower opening, the highest desirable negative heterosis (-12.88%) was recorded in HAJARI × BG-581. Heterosis for days to first edible

harvest ranged between -10.78% and 5.22%, further supporting the presence of early-harvesting hybrids, which was aligned with the present study.

Heterosis over mid-parent for fruit length (cm) and diameter (cm)

For fruit length, heterosis over mid-parents ranged from -8.16% (BG-55 × BG-01) to 46.21% (BG-53 × BG-16). Out of the thirty hybrids, seventeen exhibited significant positive heterosis, indicating good prospects for enhancing fruit elongation. The highest heterosis (46.21%) was recorded in BG-53× BG-16, followed by BG-55 × BG-53 (31.63%), BG-16 × BG-53 (29.28%), BG-53 × BG-42 (27.08%), BG-42 × BG-53 (24.99%), BG-53 × BG-01 (23.90%), and BG-01 × BG-42 (21.87% and 21.75%).

For fruit diameter, heterosis over mid-parent exhibited wide range of variation, which ranged from -26.56% (BG-53 × BG-16) to 11.65% (BG-42 × BG-55). Among the thirty crosses, thirteen showed significant negative and two displayed significant positive heterosis. The highest desirable positive heterosis was found in BG-42 × BG-55 (11.65%), followed by BG-53 × BG-21 (6.03%). Conversely, crosses expressed negatively significant heterosis i.e reduction in fruit diameter included BG-53 × BG-16 (-25.56%), BG-55 × BG-01 (-18.94%), BG-21 × BG-42 (-17.76%), BG-55 × BG-21 (-13.67%), BG-21 × BG-16 (-12.58%), BG-55 × BG-16 (-12.20%), BG-01 × BG-16 (-10.74%), and BG-21 × BG-01 (-10.69%). These crosses are useful where reduced fruit diameter is preferred for based on market demand. The present findings were aligned with the results reported by Islam (2017), who documented mid-parent heterosis for fruit length ranging from –6.22% to 22.29%, with 13 out of 21 hybrids showing significant heterosis (twelve positive). The highest heterosis was observed in BG-581 × BG-522 (22.29%), followed by BG-498 × BG-581 (18.34%), BG-657 × BG-581 (14.00%), BG-582 × BG-489 (11.00%), and BG-498 × BG-657 (10.50%). For fruit diameter, seven hybrids exhibited significant negative and nine significant positive heterosis, with the highest value recorded in Hajari × BG-657 (12.18%), followed by Hajari × BG-489 (9.51%), Hajari × BG-522 (8.02%), BG-657 × BG-522 (7.97%), and BG-498 × BG-657 (7.36%).

Similarly, Ghuge *et al.* (2016) reported mid-parent heterosis values ranging from –15.1% to 19.9% for fruit length and –24.6% to 9.46% for fruit diameter. These ranges were closely match the present investigation, confirming substantial genetic variability and the potential for improving fruit size traits through heterosis breeding in bottle gourd.

Table 4.4.7: Heterosis over Mid-Parent (%) of the crosses for earliness, yield and quality traits in bottle gourd

Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	-1.54	-9.30*	-0.39	0.25	-10.74**	-18.58**	-59.76**	-60.12**	10.03**	7.73**	-16.82**
BG-01 × BG-21	-9.69**	-1.08	-8.38**	17.65**	2.34	-5.74	32.75**	29.32**	43.25**	21.39**	14.32**
BG-01 × BG-42	-0.89	-4.17	-3.88*	21.87**	1.18	2.96	-26.73**	-22.63**	-1.59	21.43**	-10.56**
BG-01 × BG-53	0.18	4.95	-2.76	13.87**	1.80	7.93*	-13.23	-7.72	-22.87**	-16.24**	-12.02**
BG-01 × BG-55	-3.45	10.11*	-0.77	7.16	-5.42	0.32	-20.71**	-20.37**	-13.86**	41.35**	4.41**
BG-16 × BG-21	-0.16	5.15	-2.16	4.82	3.16	5.07	0.35	5.41	26.32**	23.65**	5.23**
BG-16 × BG-42	-2.77	-16.00**	-2.62	21.75**	-6.11*	3.04	-14.84	-7.70	-34.23**	-15.01**	-7.49**
BG-16 × BG-53	-0.69	-16.19**	3.60*	29.28**	-2.79	2.99	2.62	8.67*	-9.84**	-0.50	-4.87**
BG-16 × BG-55	0.34	18.28**	-0.04	19.02**	-2.02	-9.85**	-30.37**	-42.64**	-15.97**	15.07**	-24.05**
BG-21 × BG-42	-10.88**	0.93	-8.13**	13.76*	-17.76**	10.12**	-24.15**	-24.05**	7.54**	34.95**	-2.25**
BG-21 × BG-53	12.36**	-8.93*	6.98**	3.05	-7.69*	6.49*	29.93**	34.23**	10.30**	27.53**	-1.24*
BG-21 × BG-55	-5.06*	-4.00	3.30*	17.93**	-9.40**	13.72**	-9.42*	-0.95	-2.06	9.88**	7.89**
BG-42 × BG-53	0.16	-9.57*	2.81	24.99**	2.51	24.24**	13.79**	26.58**	53.42**	-11.00**	-11.94**
BG-42 × BG-55	-0.37	4.85	0.72	16.60**	11.65**	13.78**	-36.16**	-34.14**	-17.75**	-1.83	-0.48
BG-53 × BG -55	5.04*	42.59**	10.39**	17.73**	-5.26	10.30**	-58.53**	-55.63**	66.08**	40.19**	-0.58

Here, *p≤0.05 and **p≤0.01 level of probability.

Table 4.4.8: Heterosis over Mid-Parent (%) of the reciprocal crosses for earliness, yield and quality traits in bottle gourd

Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	-2.32	9.30	-0.20	3.59	2.36	21.50**	-2.99	9.66*	-23.58**	-14.05**	-4.72**
BG-21 × BG-01	-4.01	24.73**	-3.17	-0.37	-10.69**	-22.38**	-37.07**	-51.27**	-17.82**	-13.56**	6.43**
BG-21 × BG-16	6.92**	23.71**	9.97**	13.88**	-12.58**	-10.75**	-57.69**	-60.21**	-20.15**	3.96**	-3.70**
BG-42 × BG-01	-2.38	0.00	-1.60	-1.96	-4.59*	-0.99	-33.39**	-33.50**	-5.85**	5.98**	6.57**
BG-42 × BG-16	-6.76**	4.00	-3.82*	7.46	-2.39	11.39**	-9.72*	4.77	-41.26**	20.59**	-1.11*
BG-42 × BG-21	0.82	4.67	-1.35	8.07	-8.96**	-5.22	-45.80**	-47.13**	-31.07**	21.36**	-3.78**
BG-53 × BG-01	-6.15*	12.87**	-1.14	23.90**	2.29	24.84**	22.26**	47.22**	12.40**	9.71**	0.15
BG-53 × BG-16	6.88**	8.57*	3.12	46.21**	-26.56**	1.07	56.25**	78.78**	3.83**	1.49	-0.86
BG-53 × BG-21	-3.08	-7.14	-4.88**	18.17**	6.03*	7.51*	27.70**	26.91**	0.78	-2.13	-2.17**
BG-53 × BG-42	-4.82	-0.87	1.09	27.08**	1.73	25.82**	-16.30**	4.13	20.55**	-8.01**	-1.68**
BG-55 × BG-01	0.50	3.37	0.68	-8.16	-18.94**	-7.44*	-54.26**	-49.87**	6.44**	7.47**	3.46**
BG-55 × BG-16	-1.54	9.68*	-3.83*	2.94	-12.20**	-19.38**	-22.66**	-38.00**	-0.34	21.84**	7.20**
BG-55 × BG-21	-6.83**	10.00**	-3.38*	2.57	-13.67**	-0.94	-29.68**	-30.12**	16.22**	28.20**	16.72**
BG-55 × BG-42	-6.49**	6.80	-3.86*	11.90	-3.76	16.83**	31.55**	35.70**	1.46	-18.19**	4.07**
BG-55 × BG-53	-6.67**	-12.96**	-5.79**	31.63**	-3.41	18.94**	4.08	11.45*	-2.74*	36.28**	-10.65**

Here, *p≤0.05 and **p≤0.01 level of probability.

Heterosis over mid-parent for yield-contributing traits

For fruit weight, heterosis over the mid-parent value ranged from -22.38% (BG-21 × BG-01) to 25.82% (BG-53 × BG-42). Among the thirty hybrids, fourteen crosses showed significant positive heterosis, while six expressed significant negative heterosis. The highest positive heterosis (25.82%) was recorded in BG-53 × BG-42, followed by BG-53 × BG-01 (24.84%), BG-42 × BG-53 (24.24%), BG-16 × BG-01 (21.50%), BG-55 × BG-53 (18.94%), BG-42 × BG-53 (17.99%), BG-55 × BG-42 (16.83%), BG-42 × BG-53 (13.78%), BG-21 × BG-55 (13.72%), BG-42 × BG-16 (11.39%), and BG-21 × BG-42 (10.12%) for fruit weight. These results indicated that these crosses had substantial and strong potential for improving fruit weight through heterosis breeding.

For number of fruits per plant, a broad ranged of mid-parent heterosis exhibited from -59.76% (BG-01 × BG-16) to 56.25% (BG-53 × BG-16). Among the thirty crosses, seventeen showed significant negative heterosis and seven exhibited significant positive heterosis. The best performed hybrid was BG-53 × BG-16 (56.25%), followed by crosses BG-01×BG-21 (32.75%), BG-55×BG-42 (31.55%), BG-21×BG-53 (29.93%), BG-53×BG-21 (27.70%), BG-53×BG-01 (22.26%), and BG-42×BG-53 (13.79%), respectively. These results confirmed that considerable genetic variation for number of fruits per plant and strong breeding potential for exploitation of heterosis.

For yield per plant, heterosis ranged widely from -60.21% (BG-21 × BG-16) to 78.78% (BG-53 × BG-16). Among the examined hybrids, fourteen hybrids were manifested significant negative heterosis, while nine expressed significant positive heterosis for this trait. The highest heterosis over mid-parent (78.78%) exhibited in BG-53 × BG-16, followed by BG-53 × BG-01 (47.20%), BG-55 × BG-42 (35.70%), BG-21 × BG-53 (34.23%), BG-01 × BG-21 (29.32%), BG-53 × BG-21 (26.91%), BG-42 × BG-53 (26.58%), and BG-16 × BG-01 (9.66%). These results confirmed the existence of strong heterotic effects on fruit yield, particularly in crosses involving parent BG-53. Similar findings were also reported by researchers. Quamruzzaman *et al.* (2019) documented mid-parent heterosis for yield per plant ranging from 7.7% to 31.8%, with the highest heterosis in P2 × P3 (31.8%). Three hybrids exhibited >20% heterosis (P2 × P3, P2 × P4, P2 × P5), which close agreement with the current observations of high-yielding heterotic combinations. Similarly, Ghuge *et al.* (2016) reported mid-parent heterosis ranging from -22.1% to 22.4% for fruit weight, -28.2% to 17.9% for fruit number, and -35.2% to 23.9%

for yield per plant. They found fourteen, twelve, and nine crosses, respectively, with desirable significant heterosis that were consistent with the present investigation, indicated the potential of heterosis breeding for improving yield components in bottle gourd under heat stress environments in summer season.

Heterosis over mid-parent for quality traits

A substantial range of heterosis was observed for the key fruit quality parameters, indicating the presence of considerable genetic variability and strong scope for hybrid improvement under heat-stress conditions. For total soluble solids (°Brix), heterosis over the mid-parent exhibited a wide range from -41.26% in BG-42 × BG-16 to 66.08% in BG-53 × BG-55. Among the thirty hybrids evaluated, twelve expressed significant positive heterosis, while fourteen showed significant negative heterosis (table 4.4.7 and 4.4.8). The cross BG-53 × BG-55 recorded the highest positive heterosis (66.08%), followed by BG-42 × BG-53 (53.42%), BG-01 × BG-21 (43.25%), BG-16 × BG-21 (26.32%), and BG-53 × BG-42 (20.55%), identified these hybrids as promising candidates for increasing sweetness as well as fruit palatability.

For dry matter content (mg/100 g), heterosis ranged from -18.19% (BG-55 × BG-42) to 41.35% (BG-01 × BG-55). A total of eighteen hybrids displayed significant positive heterosis, while seven expressed significant negative heterosis, demonstrating a strong heterotic response for dry matter improvement. The highest heterotic advantage was observed in cross BG-01 × BG-55 (41.35%), closely followed by BG-53 × BG-55 (40.19%), BG-55 × BG-53 (36.28%), BG-21 × BG-42 (34.95%), BG-55 × BG-21 (28.20%), and BG-21 × BG-53 (27.53%). These crosses exhibited high potential for developing nutritionally superior bottle gourd hybrids.

For ascorbic acid content (mg/100 g), heterosis over the mid-parent varied from -24.05% (BG-16 × BG-55) to 16.72% (BG-55 × BG-21). Among the hybrids, eleven were expressed significant positive heterosis, whereas sixteen showed significant negative heterosis. The most desirable performance was recorded in BG-55 × BG-21 (16.72%), followed by BG-01 × BG-21 (14.32%), BG-21 × BG-55 (7.89%), BG-55 × BG-16 (7.20%), BG-42 × BG-01 (6.57%), and BG-21 × BG-01 (6.43%), indicating strong potential for improving antioxidant concentration under high-temperature environments.

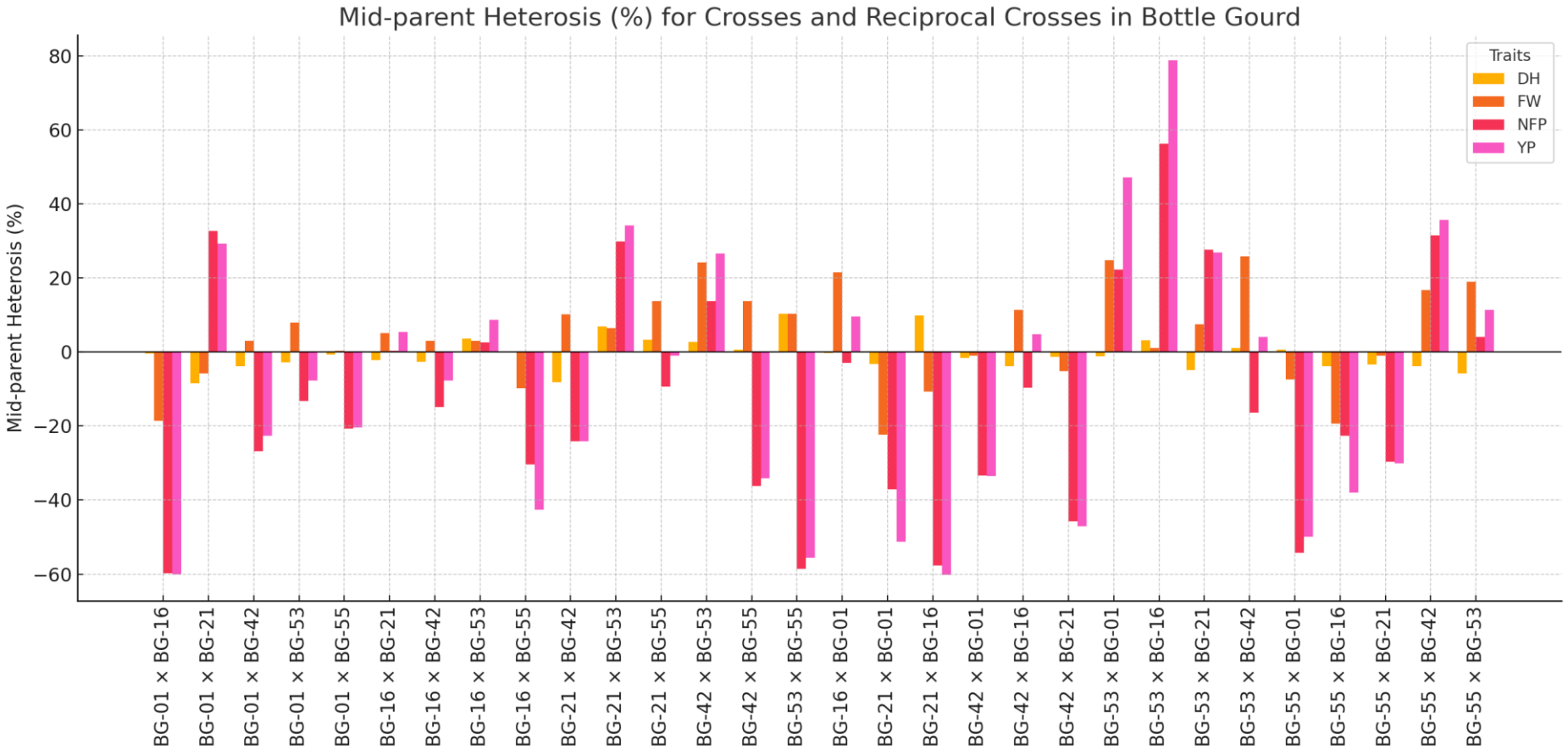


Figure 4.4.3. Mid parent heterosis (%) for days to first edible harvest (DH), fruit weight (FW), fruits per plant (FPP), and yield per plant (YP) in bottle gourd crosses and reciprocal crosses

The current findings were consistent with earlier reports. Bhatt *et al.* (2023) recorded wide ranged of heterosis for dry matter (-33.61% to 88.05%), ascorbic acid (-30.84% to 57.46%), and TSS (-20.29% to 48.44%), with several crosses exhibited significant positive heterosis which fuuly supported the heterotic trends observed in this study. Saryam *et al.* (2024) similarly reported significant heterosis for TSS (27.16%) and ascorbic acid (13.08%) in promising hybrids, aligned with the superior performance of the present crosses under the study. Rambabu *et al.* (2021) also documented mid-parent heterosis for TSS ranging from -8.62% to 53.16% and for ascorbic acid from -5.42% to 33.73%, identified top performed hybrids such as RJBGC-118 × Pusa Samridhi and BOGVAR-2 × Pusa Samridhi, which parallel to the findings of the high heterosis values observed in the current investigation. These findings confirmed that the studied hybrids possessed substantial heterotic potential for improving sweetness, nutritional density, and ascorbic acid (vitamin C) content in bottle gourd under heat-stress conditions.

4.4.2.2 Heterosis over better parent (heterobeltosis)

Heterosis over better parent for earliness traits

For days to first female flower appearance, heterosis over better parent varied widely ranged from -16.56% (BG-01 × BG-16) to 7.10% (BG-21 × BG-53). Among the thirty hybrids, nineteen exhibited significant negative and desirable heterosis, while two crosses showed positively significant but undesirable heterosis (Table 4.4.9 and Table 4.4.10). The most desirable heterobeltosis were observed in hybrid BG-01 × BG-16 (-16.56%), followed by BG-42 × BG-16 (-12.32%), BG-21 × BG-01 (-11.31%), BG-21 × BG-42 (-11.24%), BG-42 × BG-01 (-10.15%), BG-55 × BG-53 (-9.92%), BG-01 × BG-55 (-9.72%), BG-53 × BG-42 (-9.63%), BG-53 × BG-01 (-9.19%), BG-01 × BG-42 (-8.77%), and BG-16 × BG-42 (-8.57%). These results indicated strong opportunities for improving earliness through heterosis breeding.

For node number at first female flower appearance, heterosis over better parent ranged from -26.67% (BG-16 × BG-53) to 28.33% (BG-53 × BG-55). Among the thirty hybrids, eleven were expressed significant negative and desirable heterosis, while two exhibited significant positive heterosis. The most desirable crosses were BG-16 × BG-53 (-26.67%), BG-16 × BG-42 (-23.64%), BG-55 × BG-53 (-21.67%), BG-01 × BG-42 (-16.36%), BG-21 × BG-53 (-15.00%), BG-53 × BG-21(-13.33%), BG-42 × BG-53 (-13.33%), BG-01 ×

BG-16 (-13.33%), and BG-42 × BG-01 (-12.73%) for node at first female flower appearance indicated their existence of early flowering.

For days to first edible fruit harvest, heterobeltosis ranged from -13.94% (BG-01 × BG-21) to 5.32% (BG-53 × BG-55). A total of seventeen hybrids displayed significant desirable negative heterosis, whereas two crosses expressed positive and undesirable heterosis. The most desirable and negatively significant crosses included BG-01 × BG-21 (-13.94%), BG-55 × BG-16 (-9.87%), BG-01 × BG-42 (-9.87%), BG-42 × BG-16 (-9.33%), BG-21 × BG-01 (-9.05%), BG-53 × BG-21 (-8.54%), BG-21 × BG-42 (-8.31%), and BG-16 × BG-42 (-8.20%). Conversely, BG-53 × BG-16 (5.32%) and BG-21 × BG-16 (3.86%) exhibited undesirable positive heterosis for days to first making these as promising for early maturing. Ray *et al.* (2015) also reported wide variability in heterobeltosis for earliness traits, ranging from –19.29% to 34.25% for days to first pistillate flower anthesis, 36.04% to 48.14% for node number to first pistillate flower, and -11.85% to 23.00% for days to first fruit harvest, which were identical with the findings of the current research. Similarly, Rahaman *et al.* (2025) reported heterobeltosis for days to first edible fruit harvest ranging from -15.30% to 2.77%, with sixteen of twenty-one crosses showing desirable negative heterobeltosis, similar to the current results. Likewise, Islam (2017) found substantial negative heterobeltosis for earliness traits. For node number of the first female flower, heterobeltosis ranged from -13.51% to -16.10%, with fourteen significant hybrids. For days to 50% female flower opening, the best value was 25.56% (HAJARI × BG-581). For days to first edible harvest, heterobeltosis varied from -21.79% to 4.16%, with sixteen crosses showed significant negative effects. These reports strongly supported the current findings.

Heterosis over better parent for fruit length (cm) and diameter (cm)

For fruit length, heterosis over better parent ranged from -34.53% (BG-55 × BG-01) to 33.33% (BG-53 × BG-16). Among the thirty hybrids, one cross exhibited significant positive heterosis, whereas twelve crosses showed significant negative heterosis over the better parent. The most promising hybrids for fruit length improvement were BG-53 × BG-16 (33.33%), followed by BG-16 × BG-53 (17.89%), BG-53 × BG-21 (11.80%), BG-42 × BG-55 (11.48%), BG-01 × BG-21 (10.83%), and BG-53 × BG-01 (10.82%). These crosses demonstrated considerable potential for increasing fruit elongation through heterosis breeding.

Table 4.4.9: Heterosis over better parent (%) of the crosses for earliness, yield and quality traits in bottle gourd

Crosses	Days to first female flower appearance	Node Number of first female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	-3.76	-13.33**	-0.96	-17.30**	-19.77**	-20.57**	-60.58**	-60.62**	9.14**	-4.50**	-17.82**
BG-01 × BG-21	-16.56**	-11.54**	-13.94**	10.83**	-2.49	-8.28**	20.06**	21.06**	40.98**	7.20**	12.85**
BG-01 × BG-42	-8.77**	-16.36**	-9.87**	-10.63**	-14.96**	-4.48	-37.43**	-35.74**	-15.89**	13.15**	-15.77**
BG-01 × BG-53	-3.06	-11.67**	-5.11**	1.85	-2.91	5.29	-16.57**	-11.45**	-23.50**	-26.30**	-18.56**
BG-01 × BG-55	-9.72**	2.08	-7.51**	-23.61**	-22.99**	-5.30	-23.28**	-22.37**	-21.27**	24.43**	-0.08
BG-16 × BG-21	-5.76*	-1.92	-7.59**	-9.07*	-2.99	-0.19	-10.91**	-2.48	23.33**	23.10**	5.14**
BG-16 × BG-42	-8.57**	-23.64**	-8.20**	4.58	-12.98**	-2.15	-28.51**	-24.10**	-43.41**	-19.47**	-11.87**
BG-16 × BG-53	-1.70	-26.67**	1.67	17.89**	-16.21**	2.99	-3.27	3.03	-11.29**	-1.34	-10.95**
BG-16 × BG-55	-4.11	14.58**	-6.33**	-1.51	-12.41**	-12.85**	-33.96**	-44.76**	-22.62**	14.15**	-26.45**
BG-21 × BG-42	-11.24**	-1.82	-8.31**	-13.10**	-27.96**	-0.39	-28.88**	-33.24**	-9.30**	27.32**	-6.81**
BG-21 × BG-53	7.10**	-15.00**	2.87	-2.50	-15.92**	1.16	21.90**	30.79**	9.44**	27.01**	-7.47**
BG-21 × BG-55	-6.28**	-7.69	2.45	-12.65**	-23.26**	4.62	-15.53**	-5.00	-11.76**	9.49**	4.56**
BG-42 × BG-53	-4.90*	-13.33**	-1.32	-0.54	-17.07**	17.99**	0.53	8.81	30.23**	-16.35**	-13.54**
BG-42 × BG-55	-2.04	-1.82	0.08	11.48**	7.35**	11.70**	-43.92**	-44.15**	-23.64**	-7.69**	-2.15
BG-53 × BG-55	1.37	28.33**	5.32**	-9.37**	-25.61**	6.64*	-58.80**	-56.35**	50.68**	40.13**	-4.00**

Here, *p≤0.05 and **p≤0.01 level of probability.

Table 4.4.10: Heterosis over better parent (%) of the reciprocal crosses for earliness, yield and quality traits in bottle gourd

Reciprocal crosses	Days to first female flower appearance	Node Number of first female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	-4.52	4.44	-0.77	-14.54**	-8.00**	18.53**	-4.98	8.29*	-24.19**	-23.81**	-5.87**
BG-21 × BG-01	-11.31**	11.54**	-9.05**	-6.14	-14.91**	-24.47**	-43.08**	-54.38**	-19.13**	-23.67**	5.06**
BG-21 × BG-16	0.93	15.38**	3.86*	-1.21	-17.79**	-15.22**	-62.44**	-63.19**	-22.04**	3.49**	-3.78**
BG-42 × BG-01	-10.15**	-12.73**	-7.74**	-28.11**	-19.81**	-8.15**	-43.12**	-44.76**	-19.53**	-1.25	0.36
BG-42 × BG-16	-12.32**	-5.45	-9.33**	-7.69	-9.52**	5.78	-24.22**	-13.85**	-49.46**	14.26**	-5.79**
BG-42 × BG-21	0.41	1.82	-1.54	-17.45**	-20.25**	-14.26**	-49.18**	-53.53**	-41.86**	14.50**	-8.27**
BG-53 × BG-01	-9.19**	-5.00	-3.53*	10.82**	-2.44	21.79**	17.56**	41.27**	11.48**	-3.46**	-7.30**
BG-53 × BG-16	5.79*	-5.00	1.20	33.33**	-36.70**	1.07	47.27**	69.51**	2.15	0.63	-7.19**
BG-53 × BG-21	-7.62**	-13.33**	-8.54**	11.80**	-3.42**	2.12	19.80**	23.66**	0.00	-2.53*	-8.35**
BG-53 × BG-42	-9.63*	-5.00	-2.97	1.13	-17.70**	19.48**	-26.05**	-10.49*	2.33*	-13.54**	-3.47**
BG-55 × BG-01	-6.02**	-4.17	-6.16**	-34.53**	-33.99**	-12.63**	-55.75**	-51.13**	-2.71*	-5.40**	-0.98
BG-55 × BG-16	-5.91*	6.25	-9.87**	-14.82**	-21.51**	-22.06**	-26.66**	-40.29**	-8.24**	20.86**	3.81**
BG-55 × BG-21	-8.02**	5.77	-4.18**	-24.03**	-26.88**	-8.86**	-34.43**	-32.97**	4.71**	27.73**	13.11**
BG-55 × BG-42	-8.06**	0.00	-4.47**	6.99	-7.47**	14.68**	15.57**	15.08**	-5.81**	-23.08**	2.33**
BG-55 × BG-53	-9.92**	-21.67**	-10.13**	1.33	-24.15**	14.99**	3.41	9.65*	-11.76**	36.21**	-13.72**

*p≤0.05 and **p≤0.01 level of probability

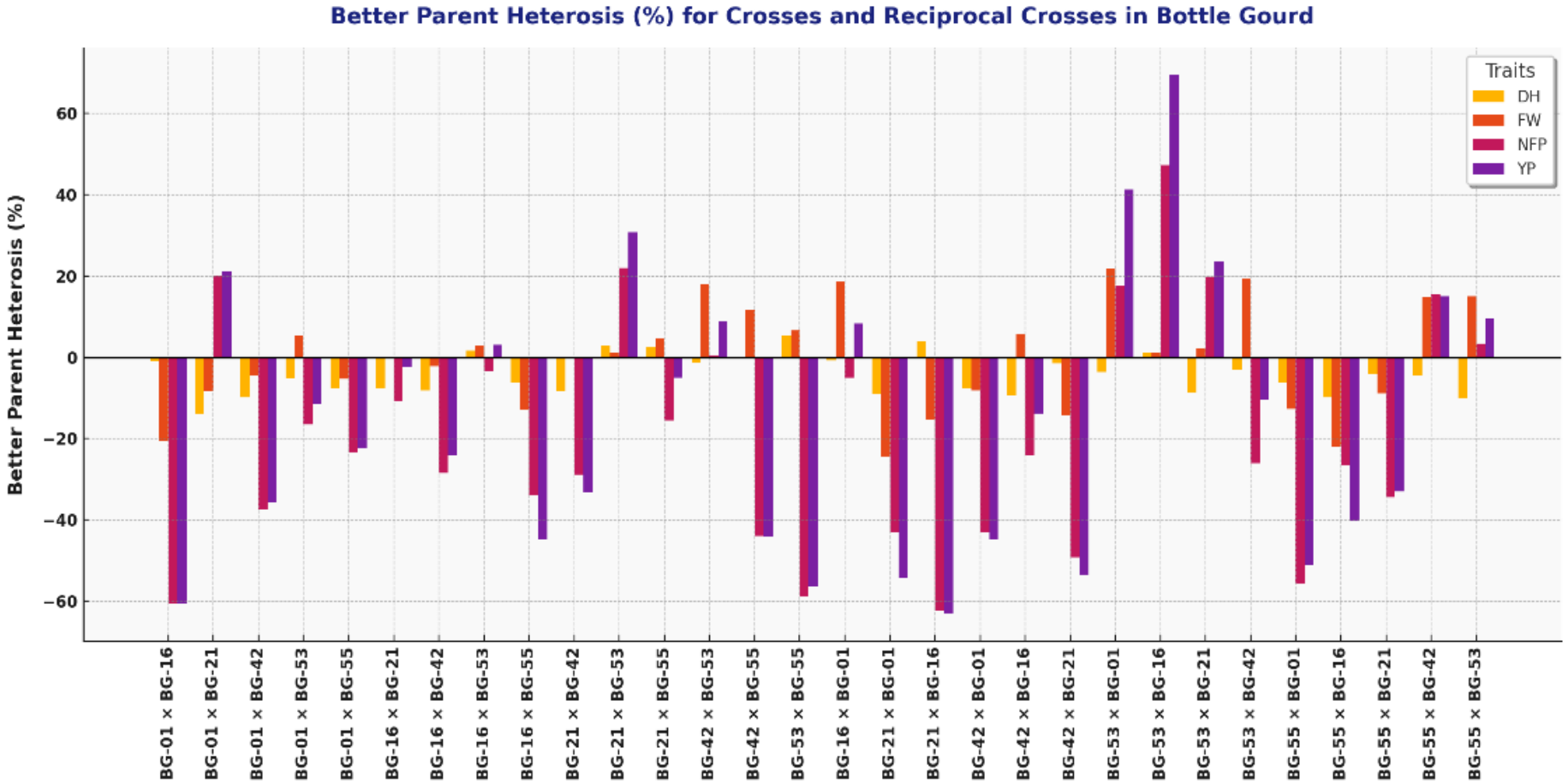


Figure 4.4.4. Better parent heterosis (%) for days to first edible harvest (DH), fruit weight (FW), fruits per plant (FPP), and yield per plant (YP) in bottle gourd crosses and reciprocal crosses

For fruit diameter, heterosis over the better parent ranged from -36.70% (BG-53 × BG-16) to 7.35% (BG-42 × BG-55). Out of the thirty cross combinations, twenty-five (25) were expressed negative heterosis, whereas only one cross showed significant positive heterosis. The only superior hybrid for diameter was BG-42 × BG-55, which exhibited 7.35% heterosis over the better parent. The fruit size traits revealed that the predominance of negative heterobeltosis suggests a tendency toward reduced fruit diameter for most combinations which might be opportunities for fruits where smaller-diameter or thinner fruits are preferred for market suitability. Ray *et al.* (2015) reported wide heterobeltosis for fruit length (−28.02% to 25.44%) and fruit circumference (−44.69% to 10.16%), indicated substantial genetic variability for fruit size traits. Likewise, Ghuge *et al.* (2016) observed mid-parent heterosis for number of fruits per vine (−28.2% to 17.9%) and fruit yield per vine (−35.2% to 23.9%), supporting the broad heterotic variation also observed in the present study.

Heterosis over better parent for yield-contributing traits

For fruit weight (kg), heterosis over the better parent ranged from -24.47% (BG-21 × BG-01) to 21.79% (BG-53 × BG-01). Among the thirty hybrids, eight crosses exhibited significant and desirable heterobeltosis. The highest positive heterobeltosis (21.79%) was recorded in BG-53 × BG-01, followed by crosses BG-53 × BG-42 (19.48%), BG-16 × BG-01 (18.53%), BG-42 × BG-53 (17.99%), BG-55 × BG-53 (14.99%), BG-55 × BG-42 (14.68%), and BG-42 × BG-55 (11.70%). These results indicated the meaningful opportunities for improving fruit weight under heat-stress conditions.

In case of number of fruits per plant, heterosis over better parents varied from -62.44% (BG-21 × BG-16) to 47.27% (BG-53 × BG-16). Among the thirty studied hybrids, six hybrids exhibited significant positive and desirable heterobeltosis, while twenty crosses were expressed negatively significant and undesirable values for number of fruits per plant. The most promising cross was BG-53 × BG-16 (47.27%), followed by BG-21 × BG-53 (21.90%), BG-01 × BG-21 (20.06%), BG-53 × BG-21 (19.80%), BG-53 × BG-01 (17.56%), and BG-55 × BG-42 (15.57%). These crosses demonstrated superior performance in terms of fruit number per plant under natural high-temperature conditions.

For fruit yield per plant (kg), heterobeltosis varied from -63.19% (BG-21 × BG-16) to 69.51% (BG-53 × BG-16). Among the evaluated thirty hybrids, seven displayed positive significant and desirable heterobeltosis, whereas seventeen showed undesirable negative

effects. The highest heterosis was observed in BG-53 × BG-16 (69.51%), followed by BG-53 × BG-01 (41.27%), BG-21 × BG-53 (30.79%), BG-53 × BG-21 (23.66%), BG-01 × BG-21 (21.06%), and BG-55 × BG-42 (15.08%). These results confirmed the strong hybrid vigor and existence of potentiality for yield improvement in specific combinations under heat-stress conditions.

The current findings were supported by previous studies. Rahaman *et al.* (2025) reported heterobeltosis for fruit yield per plant ranged from -41.12% to 26.37%, with eleven of twenty crosses showing significant positive heterosis. Balat *et al.* (2020) estimated heterobeltosis for yield varied from -22.11% to 55.03%, and were identified seven hybrids with desirable positive effects. Similarly, Quamruzzaman *et al.* (2019) found five hybrids showing significant positive better-parent heterosis (9.4%–20.5%), with P2 × P5 producing the highest value. Gautam *et al.* (2017), reported heterobeltosis ranging from -3.84% to 64.49%, with several crosses like P3 × P9, P5 × P8, P6 × P9, P4 × P5, and P2 × P4 showed exceptionally high values (58–67%). Ray *et al.* (2015) also recorded wide ranged of hetersosis over better parents ranged from -36.26% to 65.45% for fruit weight, -42.32% to 60.65% for fruit number, and -24.59% to 46.34% for fruit yield per plant, these findings were consistent with present investigation and further confirming the presence of substantial exploitable heterosis in bottle gourd.

Heterosis over better parent for quality parameters

A wide range of heterobeltosis was observed for major quality traits, highlighting substantial genetic potential for enhancing fruit sweetness, nutritional value, and antioxidant content under heat-stress conditions. For total soluble solids (°Brix), heterobeltosis ranged from -49.46% in BG-42 × BG-16 to 50.68% in BG-53 × BG-55. Out of the thirty hybrids, nine expressed significant positive and desirable heterobeltosis, whereas nineteen exhibited significant negative heterosis over better parent. The hybrid BG-53 × BG-55 was recorded the highest desirable increase (50.68%), followed by BG-01 × BG-21 (40.98%), BG-42 × BG-53 (30.23%), BG-16 × BG-21 (23.33%), BG-53 × BG-01 (11.48%), and BG-21 × BG-53 (9.44%), identified these as promising crosses for improvement of TSS for enhancing sweetness and fruit quality.

Heterobeltosis varied widely ranged from -26.30% in BG-01 × BG-53 to 40.13% in BG-53 × BG-55 for dry matter content. Among the studied crosses fifteen hybrids showed significant positive heterosis, indicating favorable allelic interactions contributing to

higher dry matter accumulation. Among the evaluated crosses, the cross BG-53 × BG-55 emerged as the best performer (40.13%), followed by BG-55 × BG-53 (36.21%), BG-55 × BG-21 (27.73%), BG-21 × BG-42 (27.32%), BG-21 × BG-53 (27.01%), and BG-01 × BG-55 (24.43%), demonstrated good prospects for improving nutritional density in bottle gourd.

For ascorbic acid content, heterosis over better parents ranged from -26.45% in BG-16 × BG-55 to 13.11% in BG-55 × BG-21. A total of seven hybrids recorded significant positive heterobeltosis, while nineteen showed significant negative values. The cross BG-55 × BG-21 showed the highest desirable improvement (13.11%), followed by BG-01 × BG-21 (12.85%), BG-16 × BG-21 (5.14%), BG-21 × BG-01 (5.06%), BG-21 × BG-55 (4.56%), and BG-55 × BG-16 (3.81%), all of crosses showed promise for enhancing vitamin C content.

These above results were closely aligned with earlier studies reporting significant heterotic expression for quality traits. Bhatt *et al.* (2023) showed heterobeltosis for dry matter ranged from -45.94% to 62.12%, with best crosses such as P2 × P7, P2 × P5, and P4 × P8. They also estimated heterois over better parent ascorbic acid content, the varied from -33.93% to 37.12%, with best crosses P2 × P7, P2 × P4, and P2 × P6; and for TSS, –25.07% to 45.90%, with promising crosses P4 × P6, P2 × P8, and P3 × P8. Similarly, Saryam *et al.* (2024) reported significant positive heterobeltosis for TSS in JBG-3 × JBG-4 (24.11%) and JBG-4 × JBG-5 (23.43%), and for ascorbic acid in JBG-4 × JBG-5 (3.45%), supporting the quality enhancing potential observed in the current study. Rambabu *et al.* (2021) reported strong heterobeltosis for quality traits, with TSS ranging from −16.73% to 33.15% and ascorbic acid from −14.08% to 33.12%. The cross RJBGC-118 × Pusa Samridhi showed the highest heterosis for TSS (53.16% over mid-parent and 33.15% over better parent), while BOGVAR-2 × Pusa Samridhi was superior for ascorbic acid (33.73% and 33.12%). These results supported the magnitude and direction of heterobeltosis observed in the present study and confirmed the potential of hybrids such as BG-53 × BG-55, BG-01 × BG-21, and BG-55 × BG-21 for quality improvement under heat-stress conditions.

4.4.2.3 Standard heterosis over commercial check varieties (Moyna, Diana and Sultan)

Commercial usefulness of any hybrids depends largely on their performance relative to the best available commercial varieties (Janaranjani *et al.,* 2016). Even a small but consistent expression of heterosis for key yield or quality components is considered valuable in hybrid development (Hathcock and Daniel, 1973). Therefore, standard heterosis serves as a critical benchmark for identifying hybrids with potential commercial suitability.

In the present study, standard heterosis was estimated over three market preferred, widely cultivated, and and popular hybrid bottle gourd varieties Moyna and Diana (short and cartoon segment) and Sultan (round, pear-spotted green segment). Evaluating hybrid performance against these commercial check varieties enables a realistic assessment of their competitive advantage. Standard heterosis thus provides an essential basis for selecting superior hybrids that can outperform established market-leading cultivars, as emphasized by Nedi *et al.* (2017). The standard heterois represented in Table 4.4.11 and Table 4.4.12 and Figure 4.4.5 for heterosis over Moyna, Table 4.4.13, Table 4.4.14 and Figure 4.4.6 for heterosis over Diana and Table 4.4.15, Table 4.4.16 and Figure 4.4.7 for heterosis over Sultan, respectively.

Standard heterosis for earliness traits

For days to first female flower appearance, standard heterosis over the check variety Moyna ranged from -13.19% (BG-53 × BG-01) to 12.96% (BG-21 × BG-53), over Diana ranged from -19.97% (BG-01 × BG-21) to 2.72% (BG-21 × BG-53), while over Sultan ranged from -18.18% (BG-01 × BG-21) to 5.15% (BG-21 × BG-53). Among the studied thirty hybrids, a total of 11, 26, and 26 hybrids exhibited significant negative and desirable heterosis over Moyna, Diana, and Sultan, respectively, indicated strong possibilities for improving earliness through hybridization.

For node number at first female flower appearance, standard heterosis over Moyna ranged from -20.39% (BG-01 × BG-16) to 57.18% (BG-53 × BG-55), standard heterosis over Diana, ranged from -33.33% (BG-01 × BG-16) to 31.62% (BG-53 × BG-55), and heterosis over Sultan varied from -24.42% (BG-01 × BG-16) to 49.22% (BG-53 × BG-55). Among these evaluated hybrids, 3, 18, and 8 crosses showed desirable negative heterosis over the check varieties Moyna, Diana, and Sultan, respectively.

For days to first edible fruit harvest, standard heterosis ranged from -6.08% (BG-01 × BG-21) to 16.86% (BG-53 × BG-55) over Moyna, -16.08% (BG-01 × BG-21) to 4.42% (BG-53 × BG-55) over Diana, and -14.27% (BG-01 × BG-21) to 6.67% (BG-53 × BG-55) over Sultan. Among the hybrids, five (5), twenty-four (24), and twenty-one (21) crosses exhibited desirable negative heterosis over Moyna, Diana, and Sultan, respectively.

Across all three commercial checks, the hybrids BG-01 × BG-21, BG-16 × BG-53, BG-16 × BG-42, BG-42 × BG-16, and BG-53 × BG-01 consistently showed significant and desirable negative standard heterosis for all key earliness traits, days to first female flower appearance, node number at first female flower, and days to first edible fruit harvest. These results confirm their potential for developing early-maturing bottle gourd hybrids under heat-stress conditions. Rahaman *et al.* (2025) documented standard heterosis for days to first edible fruit harvest ranged from -5.90% to 15.56% over Moyna, and -7.52% to 13.56% over Diana. Hybrid BG719 × BG722 exhibited the highest desirable negative heterosis (-5.90% and -7.52%), comparable to the promising hybrids identified in the present study.

Parmar and Pathak (2018) reported standard heterosis ranged from -6.22% to 11.64% for days to first female flower appearance, -42.50% to 32.50% for node number at first female flower appearance, and -4.90% to 0.82% for days to first edible harvest over the check variety Vardan. Several hybrids, such as PBOG-7 × PSPL (-6.76%) and Punjab Komal × Gutka Long (-42.50%), showed strong desirable negative heterosis, which supported the current research findings. Ghuge *et al.* (2016) recorded significant desirable standard heterosis in 28 F_1s, with PSPL × VRBG 100 showed -12.8% for pistillate flower anthesis, Aditi × VRBG VAR-45 showed -18.5% for node number to first pistillate flower, and PSPL × VRBG VAR-45 showed -14.7% for days to first fruit harvest, which aligned with the present findings. Ray *et al.* (2015) estimated standard heterosis ranging from 0.68% to 47.32% for days to first pistillate flower anthesis, -21.52% to 32.05% for node number at pistillate flowering, and 11.34% to 16.26% for days to first fruit harvest, indicatied considerable variation and were consistent with the current results.

Standard heterosis for fruit length (cm) and diameter (cm)

Standard heterosis for fruit size traits revealed considerable variability across the three commercial check varieties Moyna, Diana, and Sultan. For fruit length, heterosis ranged from -49.80% to 11.45% over Moyna, -44.07% to 24.16% over Diana, and from -3.66% to

113.87% over Sultan. The exceptionally high heterosis values over Sultan (round type) reflected the inherent morphological differences between long-fruited and round-fruited bottle gourd types. Across all check varieties, the hybrids BG-01 × BG-21, BG-53 × BG-01, and BG-53 × BG-16 consistently exhibited superior positive standard heterosis, indicating strong potential for commercialization in long-fruited market segments. For fruit diameter, standard heterosis also showed wide variation, ranged from -15.35% to 82.18% over Moyna, -33.72% to 42.64% over Diana, and -36.67% to 36.30% over Sultan. The hybrids BG-42 × BG-55, BG-55 × BG-42, and BG-16 × BG-55 displayed the highest positive heterosis across all three check varieties, demonstrated strong potential for improving fruit diameter, which is important feature in consumer preferred thicker and fleshier fruits. These findings were consistent with earlier reports. Parmar and Pathak (2018) reported standard heterosis for fruit length ranged from -46.94% to 22.90% and fruit width from -24.73% to 73.41%; Ray *et al.* (2015) documented heterosis values of -14.82% to 52.70% for fruit length and -12.24% to 30.35% for fruit circumference; and Ghuge *et al.* (2016) observed significant positive heterosis for both fruit length and diameter. These results indicated the presence of substantial exploitable heterosis for fruit size traits in bottle gourd and identified several hybrids with clear advantages over commercial standards.

Key yield contributing traits

A wide range of standard heterosis was observed for the major yield components when the hybrids were evaluated against the commercial check varieties Moyna, Diana, and Sultan. For fruit weight, the magnitude of standard heterosis varied considerably across the checks, indicated broad genetic variation among the evaluated thirty crosses derived from 6×6 full diallel mating design. Over the check variety Moyna, heterosis values ranged from -27.35% in BG-55 × BG-16 to 19.36% in BG-53 × BG-01, while over check variety Diana it ranged from -32.97% in BG-55 × BG-16 to 10.04% in BG-53 × BG-01. A similar trend of standard heterosis was observed against the round-fruited check Sultan, varied from -20.18% (BG-55 × BG-16) to 31.03% (BG-53 × BG-01). The hybrid BG-53 × BG-01 consistently expressed the highest and most desirable positive heterosis for fruit weight across all three checks, followed by BG-16 × BG-01 and BG-53 × BG-42, demonstrated their superior performance over compared commercial varieties.

Table 4.4.11: Heterosis over check variety-Moyna (%) of the crosses for earliness, yield and quality traits in bottle gourd

Check variety crosses.	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (kg)	Number of fruits per plant	Yield per plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	-9.88**	-20.39**	-3.93*	-16.84**	7.29	-22.16**	-58.08**	-59.96**	1.00	5.75**	-18.25**
BG-01 × BG-21	-12.00**	-6.10	-6.08**	11.45**	14.85**	-4.99	22.43**	20.01**	28.36**	18.70**	12.44**
BG-01 × BG-42	-2.99	-6.10	-1.26	-10.14**	33.20**	-6.39*	-36.19**	-36.30**	7.96**	25.29**	-7.44**
BG-01 × BG-53	-7.33**	8.19	-4.39*	2.41	3.56	3.19	-14.93**	-12.22**	-30.35**	-18.39**	-7.12**
BG-01 × BG-55	-7.23**	0.02	2.63	-23.19**	30.69**	-7.19*	-21.77**	-23.05**	-13.43**	37.78**	6.12**
BG-16 × BG-21	-0.61	4.10	0.85	-19.16**	29.74**	3.40	-5.26	-0.85	14.13**	5.36**	4.76**
BG-16 × BG-42	-2.78	-14.27**	0.57	-31.66**	36.30**	-8.78**	-23.98**	-22.83**	-27.36**	-22.99**	-3.16**
BG-16 × BG-53	-6.04*	-10.19*	2.44	-6.49	12.05**	-3.99	2.86	4.75	-17.91**	-15.56**	1.56**
BG-16 × BG-55	-1.47	12.27**	3.94*	-35.64**	48.65**	-18.76**	-29.78**	-43.83**	-14.93**	-2.30*	-21.89**
BG-21 × BG-42	-5.62*	10.23*	0.46	-22.74**	12.84**	3.19	-41.34**	-42.28**	16.42**	21.76**	2.40**
BG-21 × BG-53	12.96**	4.10	12.27**	-13.32**	-0.96	4.79	14.73**	19.19**	-1.99	7.74**	5.52**
BG-21 × BG-55	-1.15	-2.02	13.67**	-22.34**	30.23**	8.38**	-19.45**	-10.55*	-2.99*	-7.13**	11.04**
BG-42 × BG-53	1.13	6.14	8.11**	-21.11**	29.90**	9.98**	-5.37	-0.85	67.16**	-20.0**	-1.40
BG-42 × BG-55	4.16	10.23*	11.05**	-47.69**	82.18**	-2.80	-46.52**	-47.41**	-1.99	-11.72**	7.52**
BG-53 × BG-55	4.17	57.18**	16.86**	-28.11**	26.24**	-0.60	-60.71**	-58.90**	65.67**	18.01**	9.48**

Here, $p \leq 0.05$ and $^{**}p \leq 0.01$ level of probability.

Table 4.4.12: Heterosis over check variety-Moyna (%) of the reciprocal crosses for earliness, yield and quality traits in bottle gourd

Reciprocal crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	-10.59**	-4.06	-3.74*	-14.07**	23.04**	16.17**	1.04	10.10*	-29.85**	-15.63**	-6.36**
BG-21 × BG-01	-6.46**	18.39**	-0.74	-5.62	0.23	-21.75**	-41.96**	-54.78**	-26.37**	-15.48**	4.68**
BG-21 × BG-16	6.45**	22.47**	13.35**	-12.17**	9.93*	-12.17**	-60.05**	-62.57**	-27.86**	-11.42**	-4.12**
BG-42 × BG-01	-4.46	-2.02	1.08	-27.71**	25.61**	-9.98**	-42.00**	-45.25**	3.28**	9.35**	10.28**
BG-42 × BG-16	-6.77**	6.14	-0.67	-39.68**	41.72**	-1.40	-19.41**	-12.41**	-35.12**	9.27**	3.52**
BG-42 × BG-21	6.77**	14.31**	7.87**	-26.61**	24.92**	-11.18**	-58.08**	-59.82**	-25.37**	9.50**	0.80
BG-53 × BG-01	-13.19**	16.35**	-2.80	11.43**	4.06	19.36**	19.88**	40.04**	1.49	6.90**	5.72**
BG-53 × BG-16	1.13	16.35**	1.97	5.76	-15.35**	-5.79	56.61**	72.34**	-5.47**	-13.87**	5.84**
BG-53 × BG-21	-2.57	6.14	-0.18	-0.60	13.76**	5.79	12.76**	12.69**	-10.45**	-17.32**	4.52**
BG-53 × BG-42	-3.91	16.35**	6.30**	-19.79**	28.91**	11.38**	-30.39**	-18.43**	31.34**	-17.32**	10.08**
BG-55 × BG-01	-3.43	-6.10	4.12*	-34.17**	12.01**	-14.37**	-54.87**	-51.55**	6.97**	4.75**	5.16**
BG-55 × BG-16	-3.32	4.10	0.01	-44.34**	33.20**	-27.35**	-22.00**	-39.29**	0.90	3.45**	10.24**
BG-55 × BG-21	-2.99	12.27**	6.33**	-32.45**	24.09**	-5.59	-37.47**	-36.89**	15.12**	8.35**	20.13**
BG-55 × BG-42	-2.24	12.27**	6.00**	-49.80**	57.03**	-0.20	10.21*	8.36*	20.90**	-26.44**	12.44**
BG-55 × BG-53	-7.44**	-4.06	-0.28	-19.63**	28.71**	7.19**	-1.39	3.25	-2.99*	14.71**	-1.60

Here, *p≤0.05 and **p≤0.01 level of probability.

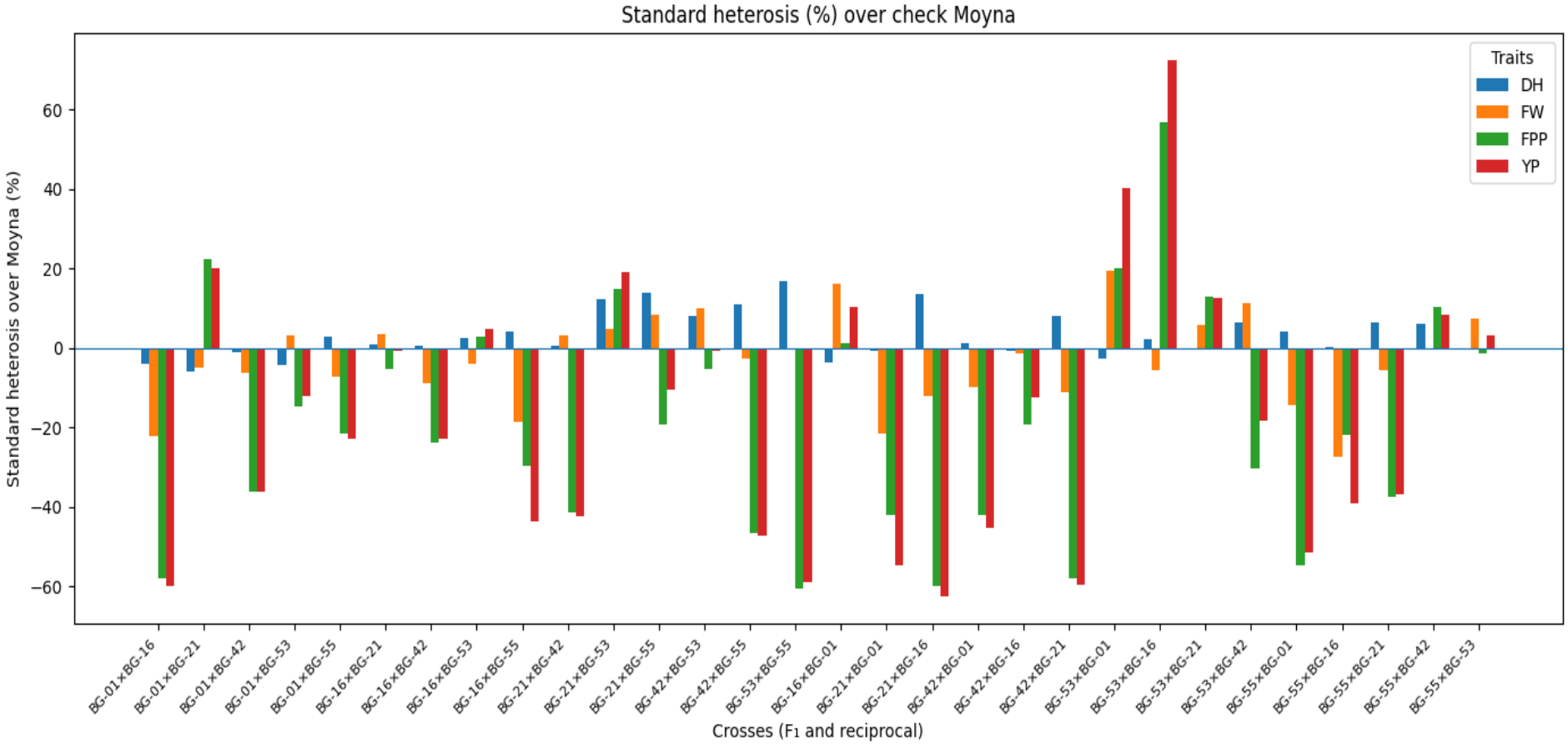


Figure 4.4.5. Standard heterosis (%) over the commercial check *Moyna* for days to first edible harvest (DH), fruit weight (FW), fruits per plant (FPP), and yield per plant (YP) in bottle gourd crosses and reciprocal crosses

Table 4.4.13: Heterosis over check variety-Diana (%) of the crosses for earliness, yield and quality traits in bottle gourd

Crosses	Days to first female flower appearance	Node Number of first female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	-18.05**	-33.33**	-14.16**	-7.35	-16.02**	-28.08**	-53.52**	-57.08**	3.15**	13.58**	-23.05**
BG-01 × BG-21	-19.97**	-21.37**	-16.08**	24.16**	-10.08**	-12.34**	35.85**	28.65**	31.10**	27.49**	5.84**
BG-01 × BG-42	-11.78**	-21.37**	-11.77**	0.11	4.26	-13.63**	-29.21**	-31.75**	10.26**	34.57**	-12.88**
BG-01 × BG-53	-15.73**	-9.40*	-14.57**	14.09**	-18.91**	-4.85	-5.62	-5.89	-28.86**	-12.35**	-12.58**
BG-01 × BG-55	-15.63**	-16.24	-8.30**	-14.43**	2.33	-14.49**	-13.20**	-17.52**	-11.59**	47.98**	-0.11
BG-16 × BG-21	-9.61**	-12.82**	-9.89**	-9.94*	1.55	-4.54	5.11	6.27	16.57**	13.17**	-1.39
BG-16 × BG-42	-11.58**	-28.21**	-10.14**	-23.86**	6.72*	-15.90**	-15.63**	-17.29**	-25.81**	-17.28**	-8.85**
BG-16 × BG-53	-14.55**	-24.79**	-8.47**	4.18	-12.27**	-11.42**	14.11**	12.29**	-16.16**	-9.30**	-4.41**
BG-16 × BG-55	-10.40**	-5.98	-7.13**	-28.30**	16.38**	-25.11**	-22.06**	-39.79**	-13.11**	4.94	-26.48**
BG-21 × BG-42	-14.17**	-7.69*	-10.24**	-13.93**	-11.68**	-4.74	-34.93**	-38.14**	18.90**	30.78**	-3.62**
BG-21 × BG-53	2.72	-12.82**	0.32	-3.43	-22.44**	-3.31	27.27**	27.77**	0.10	15.72**	-0.68
BG-21 × BG-55	-10.10	-17.95**	1.57	-13.48**	1.94	-0.09	-10.62**	-4.11	-0.91	-0.25	4.52**
BG-42 × BG-53	-8.03**	-11.11**	-3.41**	-12.11**	1.68	1.24	4.96	6.29	70.73**	-14.07**	-7.19**
BG-42 × BG-55	-5.27*	-7.69*	-0.77	-41.72**	42.64**	-10.37**	-40.65**	-43.65**	0.10	-5.19**	1.21*
BG-53 × BG-55	-5.27*	31.62**	4.42	-19.91**	-1.16	-8.47**	-56.38**	-55.95**	69.21**	26.75**	3.05**

Here, *p≤0.05 and **p≤0.01 level of probability.

Table 4.4.14: Heterosis over check variety-Diana (%) of the reciprocal crosses for earliness, yield and quality traits in bottle gourd

Reciprocal crosses	Days to first female flower appearance	Node Number of first female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	-18.69**	-19.66**	-13.99**	-4.27	-3.66	7.03*	12.11**	18.02**	-28.35**	-9.38**	-11.86**
BG-21 × BG-01	-14.94**	-0.85	-11.31**	5.15*	-21.53**	-27.75**	-35.65**	-51.53**	-24.80**	-9.22**	-1.47
BG-21 × BG-16	-3.20	2.56	1.28	-2.15	-13.95**	-19.20**	-55.67**	-59.89**	-26.32**	-4.86*	-9.76**
BG-42 × BG-01	-13.11**	-17.95**	-9.68**	-19.46**	-1.68	-17.13**	-35.65**	-41.32**	5.49**	17.45**	3.80**
BG-42 × BG-16	-15.22**	-11.11**	-11.24**	-32.80**	10.96**	-9.06**	-10.62*	-6.09	-33.74**	17.37**	-2.56**
BG-42 × BG-21	-2.90	-4.27	-3.61**	-18.23**	-2.20	-18.05**	-53.52**	-56.93**	-23.78**	17.61**	-5.12**
BG-53 × BG-01	-21.06**	-2.56	-13.15**	24.14**	-18.52**	10.04**	32.99**	50.09**	3.66*	14.81**	-0.49
BG-53 × BG-16	-8.03**	-2.56	-8.89**	17.82**	-33.72**	-12.98**	73.75**	84.73**	-3.46*	-7.49*	-0.38
BG-53 × BG-21	-11.39**	-11.11**	-10.81**	10.74*	-10.94**	-2.39	25.13**	20.78**	-8.54**	-11.19**	-1.62**
BG-53 × BG-42	-12.61**	-2.56	-5.02**	-10.64*	0.92	2.67	-22.78**	-12.57**	34.15**	-11.19**	3.62**
BG-55 × BG-01	-12.18**	-21.37**	-6.96**	-26.66**	-12.32**	-20.93**	-49.95**	-48.06**	9.25**	12.51**	-1.02*
BG-55 × BG-16	-12.08**	-12.82**	-10.64**	-37.99**	4.29*	-32.97**	-13.48**	-34.92**	3.05*	11.11**	3.77**
BG-55 × BG-21	-11.78**	-5.98	-4.99**	-24.75**	-2.84	-12.98**	-30.64**	-32.33**	17.58**	16.38**	13.07**
BG-55 × BG-42	-11.09**	-5.98	-5.29**	-44.07**	22.93**	-7.92**	22.27**	16.16**	23.48**	-20.99**	5.84**
BG-55 × BG-53	-15.83**	-19.66**	-10.89**	-10.46*	0.78	-1.14	9.40*	10.67*	-0.91	23.21**	-7.38**

Here, *p≤0.05 and **p≤0.01 level of probability.

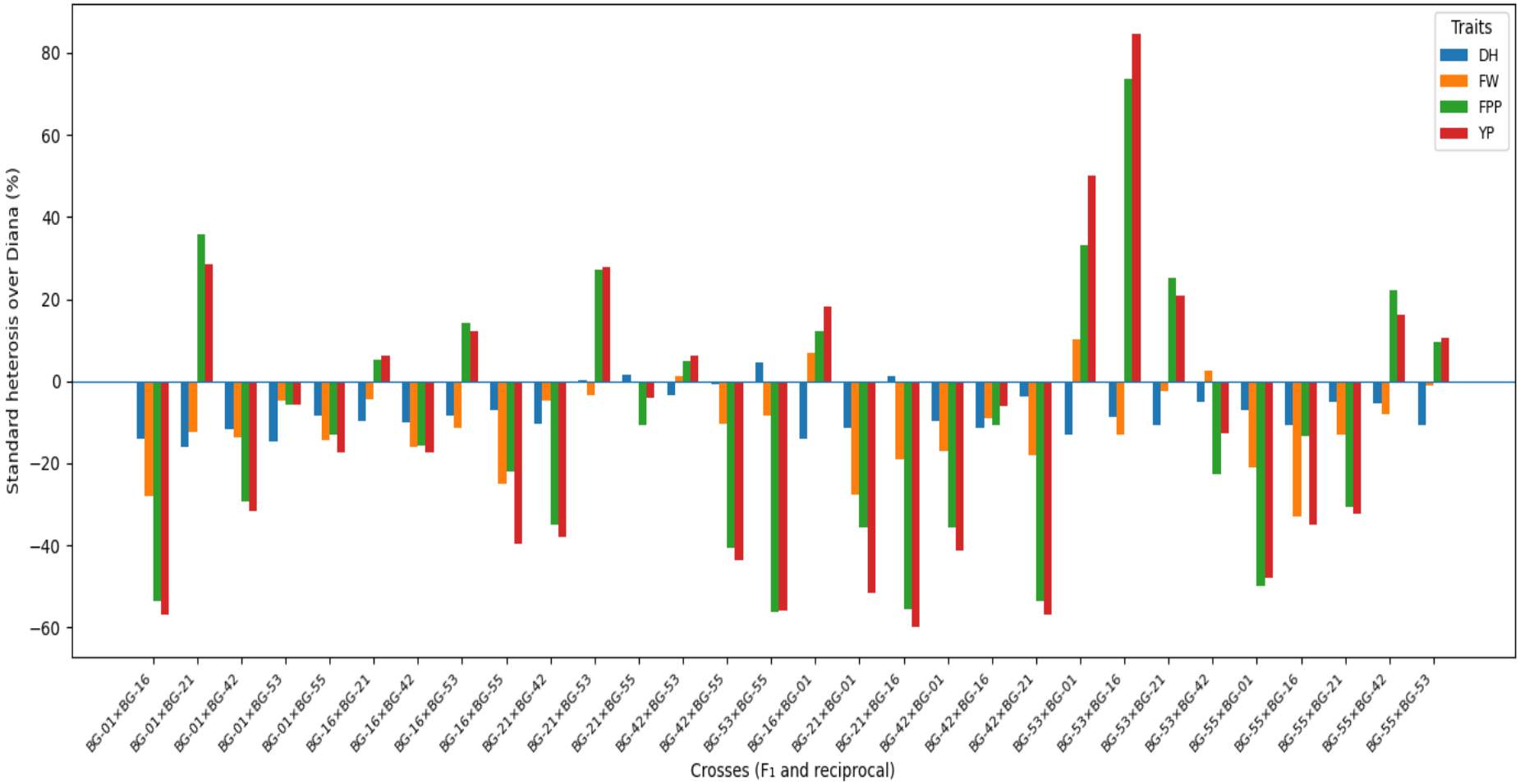


Figure 4.4.6. Standard heterosis (%) over the commercial check Diana for days to first edible harvest (DH), fruit weight (FW), fruits per plant (FPP), and yield per plant (YP) in bottle gourd crosses and reciprocal crosses

Table 4.4.15: Heterosis over check variety-Sultan (%) of the crosses for earliness, yield and quality traits in bottle gourd

Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-01 × BG-16	-16.11**	-24.42**	-12.31**	59.59**	-19.75**	-14.36**	-58.96**	-59.21**	-10.96**	27.78**	-19.88**
BG-01 × BG-21	-18.08**	-10.85**	-14.27**	113.87**	-14.07**	4.39	19.95**	22.27**	13.16**	43.43**	10.20**
BG-01 × BG-42	-9.70**	-10.85**	-9.87**	72.45**	-0.37	2.85	-37.50**	-35.14**	-4.82**	51.39**	-9.29**
BG-01 × BG-53	-13.74**	2.71	-12.74**	96.53**	-22.51**	13.30**	-16.67**	-10.57*	-38.60**	-1.39	-8.98**
BG-01 × BG-55	-13.64**	-5.04	-6.32**	47.40**	-2.22	1.83	-23.36**	-21.62**	-23.68**	66.48**	4.00**
BG-16 × BG-21	-7.47**	-1.16	-7.95**	55.14**	-2.96	13.67**	-7.20**	1.00	0.61	27.31**	2.67**
BG-16 × BG-42	-9.49**	-18.60**	-8.21**	31.15**	1.98	0.15	-25.51**	-21.40**	-35.96**	-6.94**	-5.10**
BG-16 × BG-53	-12.53**	-14.73**	-6.50**	79.45**	-16.17**	5.48	0.76	6.71	-27.63**	2.04	-0.47
BG-16 × BG-55	-8.28**	6.59	-5.13**	23.51**	11.21**	-10.82**	-31.19**	-42.78**	-25.00**	18.06**	-23.45**
BG-21 × BG-42	-12.14**	4.65	-8.31**	48.27**	-15.60**	13.43**	-42.55**	-41.21**	2.63*	47.13**	0.35
BG-21 × BG-53	5.15*	-1.16	2.48	66.35**	-25.88**	15.13**	12.37**	21.42**	-13.60**	30.19**	3.41**
BG-21 × BG-55	-7.98**	-6.98	3.76*	49.04**	-2.59	18.97**	-21.09**	-8.87*	-14.47**	12.22**	8.82**
BG-42 × BG-53	-5.86**	0.78	-1.32	51.40**	-2.84	20.56**	-7.32**	1.01	47.37**	-3.33**	-3.37**
BG-42 × BG-55	-3.03*	4.65	1.37	0.39	36.30**	6.73*	-47.60**	-46.44**	-13.60**	6.67**	5.37**
BG-53 × BG-55	-3.03*	49.22**	6.67**	37.96**	-5.56	8.99**	-61.49**	-58.13**	46.05**	42.59**	7.29**

Here, *p≤0.05 and **p≤0.01 level of probability.

Table 4.4.16: Heterosis over check variety-Sultan (%) of the reciprocal crosses for earliness, yield and quality traits in bottle gourd

Reciprocal Crosses	Days to 1st female flower appearance	Node Number of 1st female appearance	Days to 1st edible fruit harvest	Fruit length (cm)	Fruit Diameter (cm)	Fruit weight (kg)	Number of Fruit per Plant	Yield per Plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-16 × BG-01	-16.77**	-8.91*	-12.14**	64.90**	-7.94**	27.45**	-1.01	12.16**	-38.16**	1.94	-8.24**
BG-21 × BG-01	-12.93**	12.40**	-9.40**	81.12**	-25.02**	-13.96**	-43.18**	-53.93**	-35.09**	2.13	2.59**
BG-21 × BG-16	-0.91	16.28**	3.46*	68.55**	-17.78**	-3.78	-60.86**	-61.88**	-36.40**	7.04**	-6.04**
BG-42 × BG-01	-11.06**	-6.98	-7.74**	38.73**	-6.05*	-1.32	-43.18**	-44.23**	-8.95**	32.13**	8.08**
BG-42 × BG-16	-13.21**	0.78	-9.33**	15.76**	6.02*	8.29*	-21.09**	-10.75*	-42.81**	32.04**	1.45**
BG-42 × BG-21	-0.61	8.53*	-1.54	40.85**	-6.54*	-2.41	-58.96**	-59.07**	-34.21**	32.31**	-1.22*
BG-53 × BG-01	-19.19**	10.47*	-11.28**	113.84**	-22.14**	31.03**	17.42**	42.64**	-10.53**	29.17**	3.61**
BG-53 × BG-16	-5.86**	10.47*	-6.92**	102.95**	-36.67**	3.62	53.41**	75.56**	-16.67**	4.07**	3.73**
BG-53 × BG-21	-9.29**	0.78	-8.89**	90.75**	-14.90**	16.23**	10.48**	14.79**	-21.05**	-0.09	2.43**
BG-53 × BG-42	-10.55**	10.47*	-2.97	53.93**	-3.57	22.26**	-31.82**	-16.91**	15.79**	-0.09	7.88**
BG-55 × BG-01	-10.10**	-10.85**	-4.96**	26.33**	-16.21**	-5.85	-55.81**	-50.64**	-5.70**	26.57**	3.06**
BG-55 × BG-16	-10.00**	-1.16	-8.72**	6.82	-0.35	-20.18**	-23.61**	-38.15**	-11.05**	25.00**	8.04**
BG-55 × BG-21	-9.70**	6.59	-2.95	29.62**	-7.16**	3.62	-38.76**	-35.69**	1.49	30.93**	17.73**
BG-55 × BG-42	-8.99**	6.59	-3.25*	-3.66	17.47**	9.65**	7.95*	10.39*	6.58**	-11.11**	10.20**
BG-55 × BG-53	-13.84**	-8.91*	-8.97**	54.24**	-3.70	17.73**	-3.41	5.18	-14.47**	38.61**	-3.57**

Here, *p≤0.05 and **p≤0.01 level of probability.

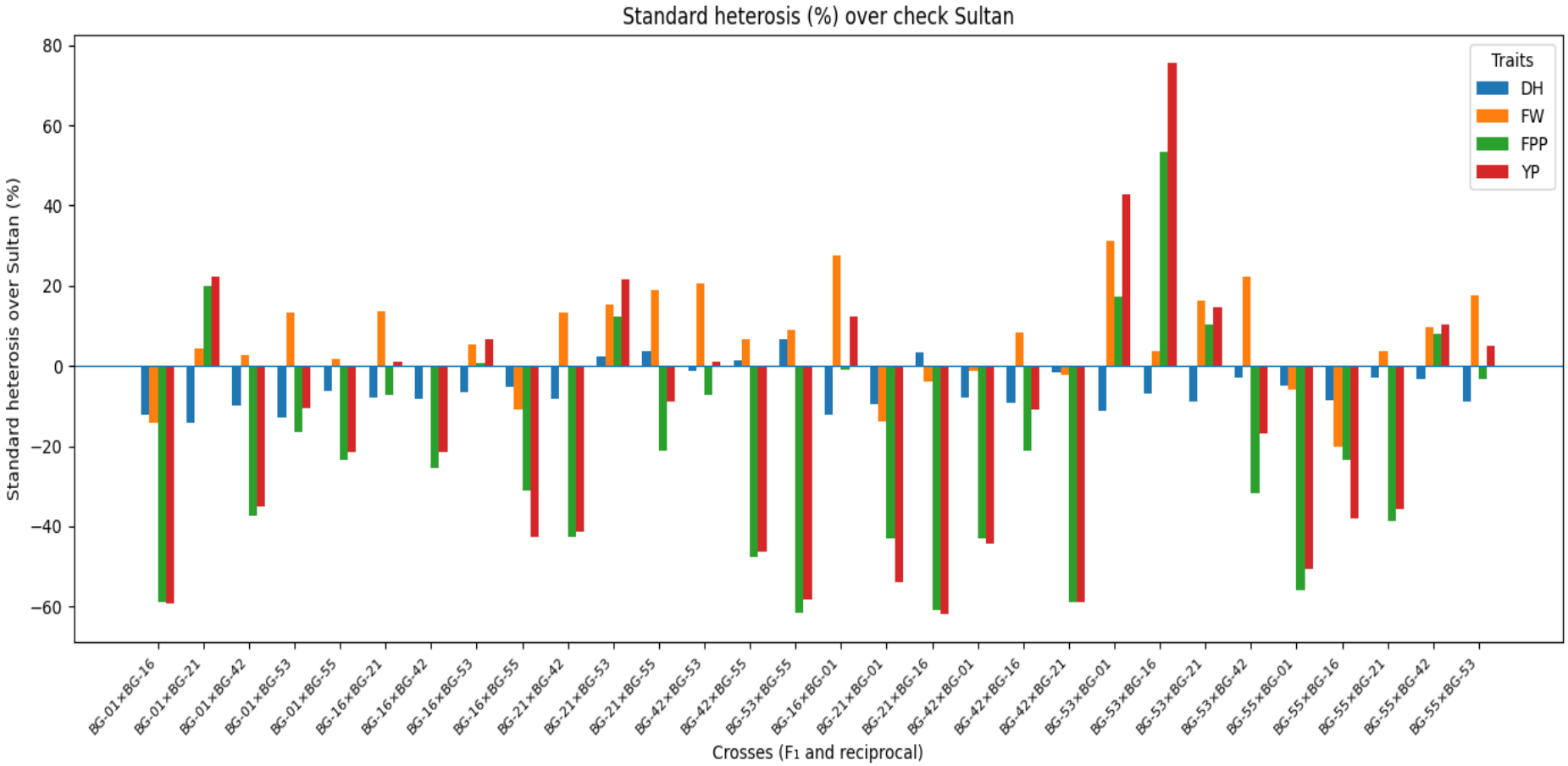


Figure 4.4.7. Standard heterosis (%) over the commercial check Sultan for days to first edible harvest (DH), fruit weight (FW), fruits per plant (FPP), and yield per plant (YP) in bottle gourd crosses and reciprocal crosses

Number of fruits per plant, a key determinant of total fruit yield, standard heterosis exhibited a wide ranged of variation among the studied hybrids. Across the check varieties, heterosis ranged from -60.71% to 53.61% over Moyna, -56.38% to 73.75% over Diana, and -61.49% to 53.41% over Sultan. Among the examined crosses, the cross BG-53 × BG-16 consistently ranked highest heterosis across all checks, recorded 56.61%, 73.75%, and 53.01% heterosis, respectively. Other notable hybrids such as BG-01 × BG-21, BG-53 × BG-01, and BG-21 × BG-53 also demonstrated superior fruit bearing capacity relative to the commercial standards. These results clearly indicated the presence of robust hybrid vigor in several combinations, especially under heat-stress conditions.

Fruit yield per plant, the most economically important trait, exhibited similar patterns of heterotic response. Standard heterosis for yield per plant varied from -59.96% to 72.34% over Moyna, -59.89% to 84.73% over Diana, and -61.88% to 75.56% over Sultan. Among the crosses, BG-53×BG-16 emerged as the most outstanding hybrid for yield, outperforming all commercial checks with heterosis values of 72.34%, 84.73%, and 75.56%, respectively. This hybrid possessed exceptional yield performance was followed by BG-53×BG-01, which also recorded consistently high positive heterosis across checks. Beside this, BG-0×BG-21 and BG-21×BG-53, expressed moderate as well as desirable improvements in total fruit yield. These trends were clearly indicated that several hybrid combinations possessed the potential to surpass current commercial varieties in yield performance, making them promising candidates for hybrid seed production and large-scale cultivation.

The findings of the present study were strongly supported by previous literature. Parmar and Pathak (2018) reported comparable ranges of standard heterosis for fruit weight, number of fruits per plant, and marketable yield, emphasizing the presence of exploitable heterotic variation in bottle gourd. Similarly, Rahaman *et al.* (2025) also identified strong positive heterosis for yield over the checks Moyna and Diana, particularly in the hybrid HAJARI × BG719, which parallels the high-yielding behavior of BG-53 × BG-16 in the present investigation. Earlier studies by Balat *et al.* (2020), Mishra *et al.* (2019), and Gautam *et al.* (2017) also documented wide ranged of standard heterosis values for yield traits, with several hybrids exceeding 50% standard heterosis which consistent with the superior yield potential observed in this study. Furthermore, Ghuge *et al.* (2016) and Ray *et al.* (2015) reported significant heterotic effects for fruit weight, fruits per vine, and yield, confirmed the identical heterosis patterns identified in this research.

Standard heterosis for quality parameters

Standard heterosis for key quality traits of bottle gourd showed wide variability across the commercial check varieties Moyna, Diana, and Sultan. For total soluble solids (°Brix), standard heterosis over Moyna ranged from -35.12% (BG-42 × BG-16) to 67.16% (BG-42 × BG-53), over Diana it varied from -33.74% (BG-42 × BG-16) to 70.73% (BG-42 × BG-53), and over Sultan ranged from –42.81% (BG-42 × BG-16) to 47.37% (BG-42 × BG-53). These results clearly indicated that BG-42 × BG-53 was the most promising hybrid for enhancing sweetness across all market leading checks, followed by BG-53 × BG-55, BG-53 × BG-42, and BG-01 × BG-21 also showed consistently high TSS improvements. For dry matter content (mg/100 g), standard heterosis over Moyna varied from -26.44% (BG-55 × BG-42) to 37.78% (BG-01 × BG-55), over Diana ranged from –20.99% (BG-55 × BG-42) to 47.98% (BG-01 × BG-55), while over Sultan dry matter heterosis extended from -11.11% (BG-55 × BG-42) to 66.48% (BG-01 × BG-55). Among the thirty hybrids, BG-01 × BG-55 expressed the highest standard heterosis across all three checks, followed by BG-01 × BG-42, BG-21 × BG-42, and BG-01 × BG-21, indicated strong potential for enhancing nutritional density, flesh thickness, and processing quality. For ascorbic acid content (mg/100 g), standard heterosis over Moyna ranged from -21.89% (BG-16 × BG-55) to 20.13% (BG-55 × BG-21), over Diana, heterosis ranged from -26.48% (BG-16 × BG-55) to 13.07% (BG-55 × BG-21), while over Sultan, values ranged from -23.45% (BG-16 × BG-55) to 17.73% (BG-55 × BG-21). The hybrid BG-55 × BG-21 consistently expressed the highest desirable increased in ascorbic acid across all checks, while BG-01 × BG-21 and BG-55 × BG-42 also recorded moderate improvements in ascorbic acid (vitamin C) concentration, making them promising candidates for improving antioxidant capacity in bottle gourd.

The overall pattern of standard heterosis for quality traits highlighted some crosses repeatedly performed superior hybrids: BG-42 × BG-53 and BG-53 × BG-55 for total soluble solids, BG-01 × BG-55 for dry matter content, and BG-55 × BG-21 for ascorbic acid content. These combinations consistently outperformed the commercial check varieties across traits and market segments, showing strong potential for inclusion in quality focused hybrid development pipelines. The present findings were in agreement with those reported by Bhatt *et al.* (2023), documented standard heterosis ranges of -50.51% to 28.04% for dry matter with top crosses such as P4 × P8, P2 × P5, and P1 × P4; -37.66% to 37.06% for ascorbic acid with best-performed hybrids P2 × P7, P2 × P6, and

P2 × P4; and -26.35% to 30.01% for TSS with superior combinations P3 × P8, P3 × P7, and P5 × P7. These previous reports strongly supported the magnitude and direction of standard heterosis observed in the present investigation and strengthen the potential of the identified hybrids for improving fruit quality under heat-stress environments.

4.4.2.4 Exploitation and selection top heterotic hybrids

Across all evaluated traits, heterosis analysis revealed substantial and exploitable hybrid vigor for earliness, fruit size, yield and quality traits in bottle gourd under heat stress conditions. Earliness showed consistently desirable negative heterosis (mid-parent, better-parent, and standard checks) in a number of hybrids especially in BG-01×BG-21, BG-16×BG-53, BG-16×BG-42, and BG-53×BG-01**,** indicated the potential for early flowering and earlier marketable harvest (Table 4.4.17). For earliness, remarkable crosses were BG-01×BG-21 (days to first edible harvest, MP–8.38%, BP -13.94%, checks -6.08%, -16.08% and -14.27% over Moyna, Diana and Sultan, days to first female flower -13.19% over Moyna), BG-16×BG-53 (days to first female: -6.04%, -14.55%, -12.53% over checks; node at first female flower MP : -16.19%; BP: -26.67%), BG-16×BG-42 (MP: node -16.00%; BP: node -23.64%) and BG-53×BG-01 (MP: days to first female flower -6.15%).

For fruit size, BG-53×BG-16 showed the highest mid-parent heterosis gains for fruit length (+46.21%) and also possessed positive standard heterosis for length across checks (e.g., heterosis over Sultan, +102.95%), while BG-42×BG-55 produced the highest standard heterosis for fruit diameter (up to +82.18% over Moyna). Crosses BG-55×BG-42 and BG-16×BG-55 also gave strong positive standard heterosis for fruit diameter (57.0% and 48.7% over Moyna, respectively). Additionally, hybrids BG-01×BG-21, BG-53×BG-01, and BG-53×BG-16 outperformed in fruit length compared to commercial checks, while BG-42×BG-55 and BG-55×BG-42 showed notable increases in fruit diameter.

For yield components, BG-53×BG-16 was the most outstanding hybrid, showed very high heterosis on fruit yield per plant of mid-parent heterosis +78.78%, better-parent heterosis 69.51%, standard heterosis 72.34% over Moyna, 84.73% over Diana, 75.56% over Sultan. BG-53×BG-01 also showed consistent yield advantages 47.22% mid-parent heterosis, 41.27% heterobeltosis, standard heterosis for fruit weight 10.04%–31.03% across checks; standard heterosis yield 40.04%–50.09% across checks. BG-01 × BG-21 exhibited 32.75% mid-parent heterosis, 21.90% heterobeltosis and 19.95-35.85% standard heterosis for number of fruits per plant.

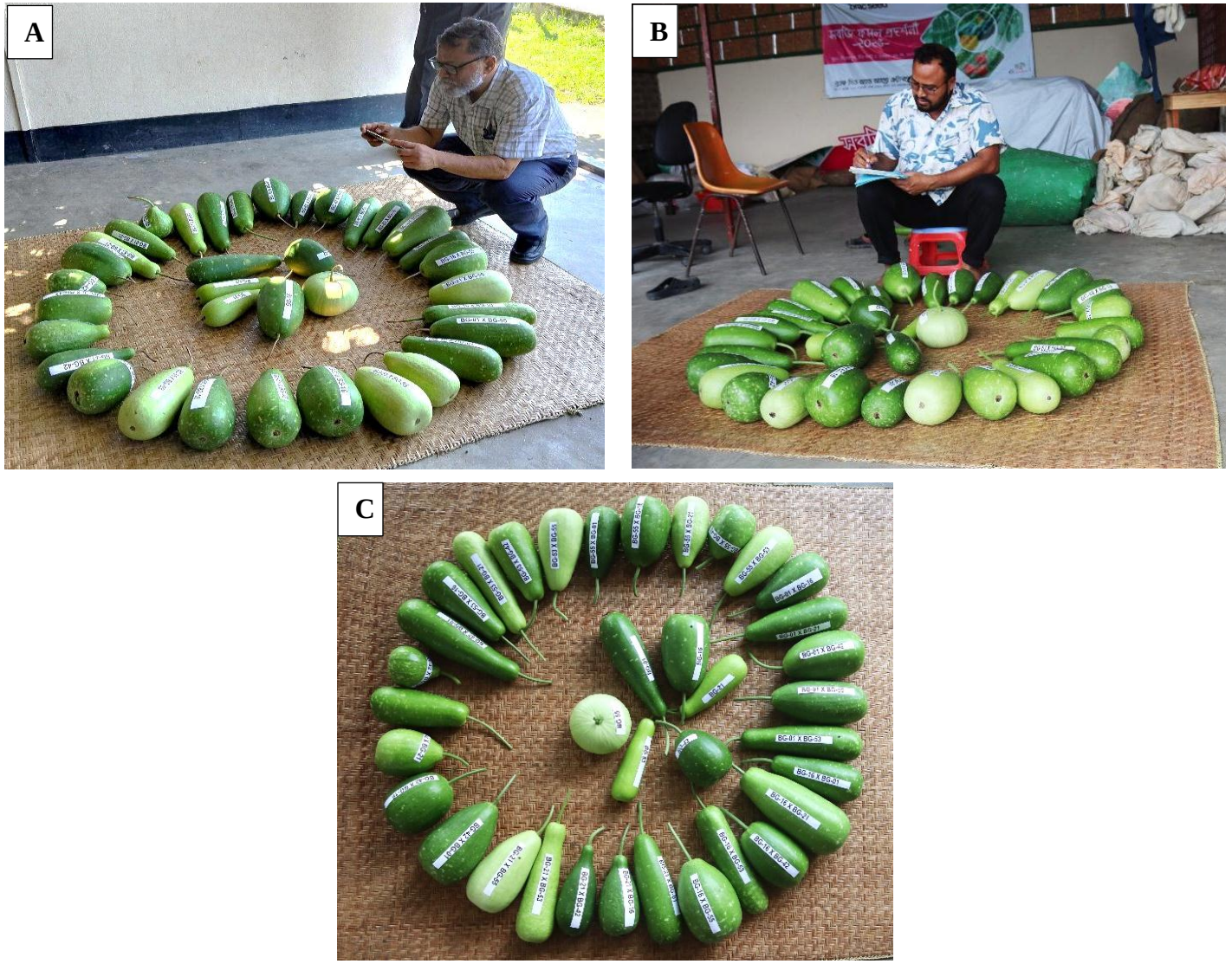


Plate 4.4.3: Fruit morphotypes of 30 hybrids (A-C) from 6 × 6 diallel crosses

Table 4.4.17: Range and magnitude of mid-parent, better parent and standard heterosis over checks Moyna, Diana and Sultan

Trait	Mid-parent heterosis (%)	Better-parent heterosis (%)	Standard heterosis (%) over Moyna	Standard heterosis (%) over Diana	Standard heterosis (%) over Sultan
Days to first female flower appearance	-10.88 to 12.36	-16.56 to 7.10	-13.19 to 12.96	-19.97 to 2.72	18.18 to 5.15
Node number of first female flower	-16.19 to 42.59	-26.67 to 28.33	-20.39 to 57.18	-33.33 to 31.62	-24.42 to 49.22
Days to first edible fruit harvest	-8.38 to 10.39	-13.94 to 5.32	-6.08 to 16.86	-16.08 to 4.42	-14.27 to 6.67
Fruit length (cm)	-8.16 to 46.21	-34.53 to 33.33	-49.80 to 11.45	-44.07 to 24.16	-3.66 to 113.87
Fruit diameter (cm)	-26.56 to 11.65	-36.70 to 7.35	-15.35 to 82.18	-33.72 to 42.64	-36.67 to 36.30
Fruit weight (kg)	-22.38 to 25.82	-24.47 to 21.79	-27.35 to 19.36	-32.97 to 10.04	-20.18 to 31.03
Number of fruits per plant	-59.76 to 56.25	-62.44 to 47.27	-60.71 to 53.61	-56.38 to 73.75	-61.49 to 53.41
Yield per plant (kg)	-60.21 to 78.78	-63.19 to 69.51	-59.96 to 72.34	-59.89 to 84.73	-61.88 to 75.56
Total soluble solids (TSS, °Brix)	-41.26 to 66.08	-49.46 to 50.68	-35.12 to 67.16	-33.74 to 70.73	-42.81 to 47.37
Dry matter content (mg/100 g)	-18.19 to 41.35	-26.30 to 40.13	-26.44 to 37.78	-20.99 to 47.98	-11.11 to 66.48
Ascorbic acid (mg/100 g)	-24.05 to 16.72	-26.45 to 13.11	-21.89 to 20.13	-26.48 to 13.07	-23.45 to 17.73

Table 4.4.18: Trait wise superior heterotic crosses in bottle gourd under heat stress conditions

Traits	Top three crosses	Heterosis (%)				
		Mid parent	Better parent	Over Moyna	Over Diana	Over Sultan
Days to first female flower appearance	BG-01×BG-21	-9.69	-11.54	-12.00	-19.97	-18.08
	BG-16×BG-53	-0.69	-1.70	-6.04	-14.55	-12.53
	BG-53×BG-01	-6.15	-9.19	-13.19	-21.06	-19.19
Node at frist female flower apperance	BG-16×BG-53	-16.19	-26.67	-10.19	-24.19	-14.73
	BG-01×BG-16	-9.30	-13.33	-20.39	–33.33	-24.42
	BG-21×BG-53	-8.93	-15.00	-4.10	-12.82	-1.16
Days to first edible fruit harvest	BG-01×BG-21	-8.38	-13.94	-6.08	-16.08	-14.27
	BG-55×BG-16	-3.83	-9.87	0.01	-10.64	-8.72
	BG-01×BG-42	-3.88	-9.87	-1.26	-11.77	-9.87
Fruit length (cm)	BG-01×BG-21	21.87	10.83	11.45	24.16	113.87
	BG-53×BG-01	23.90	10.82	11.43	24.14	113.84
	BG-53×BG-16	46.21	33.33	5.76	17.82	102.95
Fruit diameter (cm)	BG-42×BG-55	11.65	7.35	82.18	42.64	36.30
	BG-55×BG-42	-3.76	-7.47	57.03	22.93	17.47
	BG-16×BG-55	-2.02	-12.41	48.65	16.38	11.21
Fruit weight (kg)	BG-53×BG-01	24.84	21.79	19.36	10.04	31.03
	BG-16×BG-01	21.50	18.53	16.17	7.03	24.45
	BG-53×BG-42	24.24	19.48	11.38	2.67	22.26
Number of fruits per plant	BG-53×BG-16	56.25	47.27	53.61	73.75	53.41
	BG-01×BG-21	32.75	21.90	22.43	35.85	19.95
	BG-53×BG-01	22.26	19.80	19.88	32.99	17.42
Yield per plant (kg)	BG-53×BG-16	78.78	69.51	72.34	84.73	75.56
	BG-53×BG-01	47.20	41.27	40.04	50.09	42.64
	BG-01×BG-21	29.32	21.06	20.01	28.65	22.27
Total soluble solids (TSS) (°Brix)	BG-42×BG-53	53.42	30.23	67.16	70.73	47.37
	BG-53×BG-55	66.08	50.68	65.67	69.21	46.05
	BG-01×BG-21	43.25	40.98	28.36	31.10	13.16
Dry matter content (mg/100g)	BG-01×BG-55	41.35	24.43	37.78	47.98	66.48
	BG-53×BG-55	40.19	40.13	18.01	26.75	42.59
	BG-21×BG-42	34.95	27.32	21.76	30.78	47.13
Ascorbic acid content (mg/100g)	BG-55×BG-21	16.72	13.11	20.13	13.07	17.73
	BG-01×BG-21	14.32	12.85	12.44	5.84	10.20
	BG-21×BG-55	7.89	4.56	11.04	4.52	8.82

For quality, among the crosses several crosses exhibited good performed in BG-53×BG-55 had the highest heterosis over mid-parent (+66.08%), and better-parent (+50.68%) achieved for sweetness and also possessed strong standard heterosis for TSS across checks (65.67–69.21%); BG-42×BG-53 also showed the top standard heterosis for TSS over Moyna (67.16%) and Diana (70.73%); BG-01×BG-55 also possessed higher mid-parent heterosis (+41.35%), standard heterosis (66.48% over Sultan) improvements for dry matter and BG-55×BG-21 were consistently improved ascorbic acid content in mid-parent (+16.72%), better-parent (+13.11%), and standard heterosis (20.13% over Moyna).

These results identified a small set of elite hybrids such as BG-53×BG-16, BG-53×BG-01, BG-01×BG-21, BG-55×BG-42 and BG-21×BG-53 were consistently performed combined earliness, superior fruit size, high yield and improved quality. These hybrids were therefore represented the most promising candidates for advancing early harvesting and maturing, improved and marketable fruit size, high-yielding and higher-quality in confirmation trials, multi-environment evaluation and hybrid seed advancement for commercialization under heat-stress conditions.

Among the crosses, BG-53 × BG-16 expressed the strongest, most outstanding, and most consistent heterotic hybrid (Table 4.4.19, Table 4.4.20). The cross exhibited exceptionally high heterosis for yield per plant, 78.78% over the mid-parent, 69.51% over the better parent, and 72.34%, 84.73%, and 75.56% over the standard checks Moyna, Diana, and Sultan, respectively. The number of fruits also possessed higher heterosis of 56.25% over mid-parent, 47.27% over better parent, and 53.34-73.75% over checks which indicated key yield-driven traits for fruit yield per plant. Moreover, it showed substantial positive heterosis for fruit length (46.21% over mid-parent and 33.33% over better parent) and moderate improvement in quality traits such as TSS and ascorbic acid, making it the most comprehensive and commercially promising cross under heat stress conditions.

BG-01 × BG-21 showed broad-based heterotic superiority with strong mid-parent heterosis for yield (29.32%), fruit number (32.75%), fruit length (17.65%), TSS (43.85%), dry matter (21.39%), and vitamin C (14.32%). Better-parent heterosis was also notable for TSS (40.98%), vitamin C (12.85%), and earliness days to first edible fruit harvest (–13.94%). Standard heterosis also consistently positive across checks, particularly for fruit length (11.45–24.16%), TSS (13.16–31.10%), dry matter (18.7–43.43%), and yield (20.01–28.65%), indicated their potential for both productivity and quality.

BG-55 × BG-42 displayed strong mid-parent heterosis for yield (35.70%), fruit number (31.55%), fruit weight (16.83%), and fruit length (11.90%). Better-parent heterosis confirmed superiority for fruit weight (14.68%), fruit number (15.57%), and vitamin C (2.33%). Notable standard heterosis were also recorded for fruit diameter (57.03% over Moyna; 22.93% over Diana; 17.47% over Sultan), along with moderate positive heterosis for TSS and vitamin C, marking this hybrid as superior for fruit diameter related traits and overall yield.

Similarly, BG-21 × BG-53 were exhibited strong mid-parent heterosis for yield (34.23%), fruit number (29.93%), dry matter (27.53%), and TSS (10.3%), with desirable negative heterosis for node of first female flower (-8.93%). Better-parent heterosis was high for yield (30.79%) and dry matter (27.01%). Standard heterosis showed positive gains for yield (19.19–27.77%), fruit number (14.73–27.27%), and vitamin C, with extremely high fruit length heterosis over Sultan (66.35%), made this hybrid excellent for yield, earliness, and long-fruited market segments.

BG-53 × BG-01 also demonstrated outstanding mid-parent heterosis for yield (47.22%), fruit weight (24.84%), fruit length (23.90%), and quality traits included TSS (12.40%) and dry matter (9.71%). Better-parent heterosis confirmed its superiority for yield (41.27%), fruit weight (21.79%), and TSS (11.48%). Standard heterosis across checks was consistently high for yield (40.04–50.09%), fruit weight (10.04–31.03%), fruit diameter and length (11.43–113.84%), and vitamin C (5.72%), positioning this hybrid as one of the strongest for overall yield, fruit size, and quality improvement.

Table 4.4.19: Summary heterosis of top five promising heterotic hybrids across traits in bottle gourd

Crosses	Heterosis over Mid-parent	Heterosis over better parent	Standard heterosis over Moyna	Standard heterosis over Diana	Standard heterosis over Sultan
BG-53 × BG-16	YP (78.78%), NFP (56.25%), FL (46.21%), TSS (3.83%)	YP (69.51%), NFP (47.27%), FL (33.33)	YP (72.34%), NFP (56.61%), FL (5.76), Vit-C (5.84%)	YP (84.73), NFP (73.75%), DH (-8.89%)	YP (75.56%), NFP (53.34%), Vit-C 3.73%
BG-01× BG-21	YP (29.32), NFP (32.75), FL (17.65), TSS (43.85), DM (21.39), Vit C (14.32%)	YP (21.06), NFP (20.06), FL (10.83), TSS (40.98), Vit-C (12.85), DH (-13.94%)	YP (20.01), NFP (22.43), FL (11.45), FD (14.85), TSS (28.36), DM (18.7), DH (-6.08%),	YP (28.65), NFP (35.85%), TSS 31.1%, DM 27.49%, Vit-C 5.84%, DH -16.08%	YP 22.27%, NFP 19.95%, TSS 13.16%, DM 43.43%, DH -14.27%
BG-55 × BG-42	YP (35.70), NFP (31.55), FW (16.83), FL (11.90), DH (-3.83%)	YP (15.08), NFP (15.57), FW (14.68), FL (6.99), DH -4.47%, Vit-C 2.33%	YP (8.36), NFP (10.21), FD (57.03), Vit-C (12.44), TSS 20.90%	YP (16.16), NFP (22.27), FD (22.93), Vit-C (5.84), TSS 23.48%, DH -5.29%	YP 10.39%, NFP 7.95%, FW 7.95%, Vit-C 10.2%, DFF -8.99%
BG-21 × BG-53	YP (34.23), NFP (29.93), FW (6.49), TSS (10.3), DM (27.53), NFF (-8.93%)	YP (30.79), NFP (21.90), DM (27.01), TSS 9.44%, NFF -15.0%	YP (19.19), NFP (14.73), FW (4.79), DM (7.74), Vit C (5.52%)	YP 27.77%, NFP 27.27, DM 15.72, NFF -12.82%	YP 21.42, NFP 12.37, FW 15.13%, FL 66.35, DM 30.19%
BG-53 × BG-01	YP (47.22), NFP (22.26), FW (24.84), FL (23.90), DFF (-6.15), TSS 12.40%, DM 9.71%	YP (41.27), NFP (17.56), FW (21.79), FL (10.82), DFF (-9.19), TSS 11.48%	YP (40.04), NFP (19.88), FD (19.36), FL (11.43), DFF (-13.19), DM (6.9), Vit C (5.72)	YP 50.09%, NFP 32.99%, FW 10.04%, FL 24.14%, DH -13.15%, DM 14.81%	YP 42.64%, NFP 17.42%, FW 31.03%, FD 113.84%, DH -11.28%

Table 4.4.20: Mean performance of five heterotic promising hybrids under heat stress conditions

Crosses	Days to first female flower appearance	Node at first female appearance	Days to first edible fruit harvest	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (kg)	Number of fruits per plant	Yield per plant (Kg)	Total soluble solids (°B)	Dry matter (mg/100 g)	Ascorbic acid (mg/100 g)
BG-53 × BG-01	44.44±0.40	19.00±0.00	57.67±0.38	36.99±0.39	10.51±0.20	1.99±0.05	10.33±0.35	19.83±0.50	3.40±0.06	4.65±0.03	8.81±0.06
BG-53 × BG-16	51.78±0.44	19.00±0.58	60.50±0.44	35.11±0.24	8.55±0.00	1.58±0.04	13.50±0.25	24.40±0.44	3.17±0.03	3.75±0.03	8.82±0.06
BG-55 × BG-42	50.06±0.55	18.33±0.33	62.89±0.84	16.67±0.22	15.86±0.18	1.67±0.02	9.50±0.42	15.34±0.74	4.05±0.03	3.20±0.06	9.37±0.09
BG-01 × BG-21	45.06±0.31	15.33±0.33	55.72±0.63	37.00±0.25	11.60±0.09	1.59±0.02	10.56±0.15	17.00±0.38	4.30±0.06	5.16±0.04	9.37±0.09
BG-21 × BG-53	57.83±1.21	17.00±0.58	66.61±2.17	28.78±0.20	10.01±0.34	1.75±0.01	9.89±0.40	16.88±0.48	3.28±0.04	4.69±0.05	8.79±0.05



A) F_1 (BG-53 × BG-16)



B) F_1 (BG-01 × BG-21)



C) F_1 (BG-21 × BG-53)



D) F_1 (BG-53 × BG-01)



E) F_1 BG-55 × BG-42

Plate 4.4.4: Fruit morphotypes of selected top five (A-E) promising hybrids



Plate 4.4.5: Field view (A-C) of promising hybrids field visited by supervisor

CHAPTER V
SUMMARY AND CONCLUSION

The present study, entitled "Selection of Heat Tolerant Parents and the Development of Superior Hybrids in Bottle Gourd [*Lagenaria siceraria* (Mol.) Standl.]", was undertaken to evaluate genetic variability, correlations, path coefficient effects on yield, stress tolerance indices, combining ability, and heterosis, with the aim of identifying superior parents and cross combinations suitable for heat-stress conditions. The research was conducted at the BRAC Vegetable Research Center, Dinajpur, Bangladesh, during 2022-2025.

Bottle gourd productivity in Bangladesh is constrained by low-yielding varieties, high heat stress, seasonal variability, and restricted adoption of hybrids. Consequently, the identification of heat-tolerant and widely adaptable genotypes is critical for the development of high-yielding hybrid varieties. A total of 58 diverse genotypes were evaluated in a randomized complete block design with three replications during Rabi 2022–23 (optimum conditions) and Kharif 2023 (natural heat stress conditions), maintaining uniform agronomic management except for sowing time.

Parental selection was performed using line × tester analysis during summer 2024 to estimate mean performance and general combining ability (GCA). Subsequently, specific combining ability (SCA) and heterosis for yield and yield-contributing traits were assessed in F_1 generations derived from a 6 × 6 diallel cross during summer 2025. Data on earliness, fruit traits, yield components, and quality parameters were analyzed statistically to identify promising parents and hybrids for the development of heat-tolerant, high-yielding bottle gourd varieties.

5.1 Study of genetic variability, correlation, and path coefficient analysis under optimum and heat stress conditions

The study revealed wide and significant genetic variability among bottle gourd genotypes for earliness, yield, yield components, and quality traits under both optimum and heat-stress conditions. Analysis of variance showed highly significant ($P < 0.01$) genotypic differences for all traits, indicating strong genetic control. Yield per plant declined markedly under heat stress (18.45 to 12.58 kg), confirming the adverse impact of high

temperature, while fruit harvest occurred earlier (71.82 to 67.89 days). Most traits exhibited very high broad-sense heritability (>90%), suggesting good prospects for genetic improvement under heat stress. Genetic variability parameters indicated that earliness traits such as days to first female flower appearance (h^2 = 94.63% in optimum; 96.47% in heat stress) and days to first edible fruit harvest (h^2 = 95.40% and 97.03%, respectively) were predominantly governed by additive gene action, as reflected by moderate to high genetic advance as a percent of mean (21.11–22.51%). Yield and its major components also exhibited high genetic variability and heritability, notably fruit length (h^2 = 99.34% optimum; 98.86% heat), fruit diameter (97.15 in optimum; 97.48% in heat stress), number of fruits per plant (86.31; 92.05%), fruit weight (98.08%, 97.29%), and yield per plant (96.26%, 98.20%). High genetic advance for number of fruits per plant (45.44% in optimum; 36.77% in heat stress) and yield per plant (46.59%; 67.17%) further confirmed the effectiveness of selection for these traits under both environments.

Correlation analysis showed that genotypic correlations were consistently higher than phenotypic correlations, indicating strong inherent genetic associations and comparatively lower environmental influence under both environments. Yield per plant exhibited strong positive correlations with number of fruits per plant (rg = 0.696; rp = 0.620) and fruit weight (rg = 0.368; rp = 0.358) under optimum conditions. It was negatively associated with days to first female flower appearance, node number of first female flower appearance (rg = –0.069; rp = –0.063), node at first female flower appearance (rg = –0.019; rp = –0.022), and days to first edible fruit harvest (rg = –0.115; rp = –0.107), suggesting that earlier flowering and maturity favor yield improvement.

The correlation coefficient for yield per plant under heat stress showed strong positive and significant associations with number of fruits per plant (rg = 0.60; rp = 0.662) and fruit weight (rg = 0.368; rp = 0.358) and showed positive relationships with fruit length and fruit diameter, indicating that higher fruit number, size, and weight contribute directly to yield. Earliness traits such as days to first female flower appearance (rg = -0.069; rp = -0.063), node number of first female flower appearance (rg = -0.019; rp = -0.022), and days to first edible fruit harvest (rg = -0.115; rp = -0.107) showed negative associations with yield, suggesting that earlier flowering and earlier fruit maturity contributed favorably to yield enhancement in bottle gourd.

Path coefficient analysis highlighted the relative importance of yield components under both environments. Under optimum conditions, number of fruits per plant exerted the highest direct effect on yield (genotypic = 0.974; phenotypic = 0.912), followed by fruit weight (0.751 and 0.703, respectively). Under heat stress, number of fruits per plant remained the most influential trait, with a strong direct effect (0.896) and high positive correlation with yield (0.807). Fruit weight showed a moderate direct effect (0.450) with a positive correlation (0.354), while fruit diameter also exhibited a substantial positive association with yield (0.434). In contrast, earliness traits such as days to first female flower appearance and days to first edible fruit harvest had negative direct or indirect effects on yield, indicating the advantage of early phenological development. Low residual effects (0.0527 under optimum; 0.154 under heat stress) suggested that the studied traits explained about 95% and 85% of yield variation, respectively. The genotypic effects were higher than the phenotypic effects, confirming the strong genetic control over environmental influence. Hence, selection for fruit number, fruit weight, and fruit diameter would be most effective for yield improvement of bottle gourd under heat stress.

5.2 Screening and identification of heat-tolerant bottle gourd genotypes using stress tolerance indices

Stress tolerance indices were evaluated for yield and key yield-contributing traits to identify heat-tolerant genotypes. Fruit diameter was moderately affected by heat stress, but genotype-dependent variation was reflected by the stress tolerance indices. Genotypes BG-42, BG-57, BG-54, BG-55, BG-37, and BG-36 showed consistently lower reduction (RC) and low Stress Susceptibility Index (SSI), and higher Stress Tolerance Index (STI) and Yield Stability Index (YSI), indicating better maintenance of fruit diameter under high temperature. In contrast, genotypes BG-04, BG-09, BG-13, BG-22, and BG-25 exhibited high RC and SSI with low STI and YSI, reflecting severe constraint in fruit diameter expansion. Stable fruit diameter under stress contributed positively to yield, particularly with sustained fruit set.

The number of fruits per plant was the most heat-sensitive trait, showing higher reductions and wide variation in stress tolerance indices. Genotypes BG-18, BG-35, BG-02, BG-57, BG-58, BG-16, and BG-36 recorded low RC, TOL, and SSI, along with high STI, GMP, HM, YI, and YSI. These index values indicated strong reproductive resilience and stable fruit set under heat stress. Conversely, nineteen genotypes produced no fruits under stress

(RC = 100%) and showed high SSI with zero STI, YI, and YSI, indicating their extreme susceptibility and failure of reproductive processes. Fruit weight response to heat stress genotypes was effectively distinguished by indices for stability and susceptibility. Genotypes BG-45, BG-39, BG-28, BG-53, BG-35, BG-36, and BG-37 exhibited low RC, TOL, and SSI, with high YSI and RSI, as well as superior MP, GMP, and HM, suggesting stable performance across environments. Genotypes with zero fruit weight under heat stress showed maximum SSI and zero STI, YI, and YSI, indicated severe disruption of fruit filling under high temperature.

For yield (t ha^{-1}), genotypes BG-02, BG-43, BG-57, BG-01, BG-45, and BG-39 combined high MP, GMP, HM, STI, and YI, identifying them as stable and productive under both conditions and considered as tolerant. BG-02, BG-45, and BG-57 were the most heat-tolerant based on low mean rank ($\bar{R}$) and SDR. Yield under stress (Ys) showed strong positive associations with MP, GMP, HM, STI, YI, YSI, and RSI, but negative associations with TOL and SSI. The PCA indicated that PC1 and PC2 explained 83.89% and 14.50% of variation (total 98.39%), and the biplot confirmed positive relationships of Yp and Ys with MP, GMP, HM, STI, YI, and YSI, and negative associations of Ys with TOL and SSI.

The combined stress tolerance indices ranking of yield and key traits (fruit diameter, number of fruits per plant, and fruit weight) revealed substantial variation among 58 genotypes for tolerance and stability under heat stress. The genotypes BG-57, BG-45, BG-36, BG-39, BG-02, BG-37, and BG-42 showed the lowest combined ranks and SDR, indicating superior and stable heat tolerance. While BG-53, BG-54, BG-21, BG-16, BG-43, BG-28, BG-55, and BG-56 exhibited moderate tolerance, nineteen genotypes with no fruit set ranked poorest. The cluster analysis grouped the genotypes into susceptible (19), tolerant (21), and mid-tolerant (18) categories, confirming the effectiveness of stress indices in differentiating heat tolerance.

5.3 Selection of heat-tolerant inbred lines based on combining ability using line × tester analysis in bottle gourd

The Line × Tester analysis in bottle gourd revealed highly significant genetic variability among lines, testers, and their interactions for all studied traits, including earliness, fruit characteristics, yield components, and yield per plant. General combining ability (GCA) analysis identified several parents with desirable additive genetic effects for early

flowering, early harvest, fruit size, number of fruits per plant, fruit weight, and yield per plant.

For earliness, lines BG-54, BG-36, BG-16, BG-07, BG-35, and BG-21 exhibited significant negative GCA effects, indicating their potential as good general combiners for early flowering and harvest. Among testers, BG-58 consistently showed favorable GCA effects for earliness traits, confirming its suitability as a good general combiner. For fruit length, BG-01, BG-28, BG-16, and BG-02 recorded the highest positive and significant GCA effects, while BG-56, BG-57, BG-55, and BG-42 showed strong positive effects for fruit diameter, identifying them as effective combiners for these traits. Regarding yield-contributing traits, lines BG-54, BG-21, BG-45, BG-35, BG-02, and BG-16 had strong GCA effects for number of fruits per plant. Fruit weight was positively influenced by BG-16, BG-07, BG-45, and BG-21, whereas BG-21, BG-54, BG-16, BG-35, and BG-42 exhibited strong positive GCA effects for yield per plant. These results indicated the predominant role of additive gene action in improving yield and its components in bottle gourd.

Mean performance analysis revealed wide phenotypic variation among the parents for all traits, indicating substantial genetic diversity among the studied genotypes. However, inconsistencies between mean performance and GCA effects for several traits emphasized the need for a pooled ranking approach. Based on the pooled ranking of the parents, BG-01 emerged as the top-performing line, followed by BG-16 and BG-21, showing stable performance and superior combining ability across most traits considered as good general combiners. Moreover, lines BG-42, BG-55, and BG-53 displayed moderate ranking with potential for specific traits, while BG-18, BG-39, BG-57, and BG-37 were consistently poor performers. For testers, both BG-03 and BG-58 achieved the lowest total ranks, confirming their efficiency as elite testers for hybrid evaluation. Consequently, three good general combiners, BG-01, BG-16, and BG-21, and three moderate combiners but trait-specific good combiners, BG-42, BG-55, and BG-53, were judiciously selected for further diallel cross mating, providing a strong foundation for hybrid development in bottle gourd.

5.4 Combining ability and heterosis analysis of selected heat-tolerant genotypes in bottle gourd through 6 × 6 diallel cross analysis

5.4.1 Analysis of variance and study of combining ability

Six diverse inbred lines, BG-01, BG-16, BG-21, BG-42, BG-53, and BG-55, selected from Experiment-III were evaluated in a full diallel analysis. ANOVA showed significant differences among crosses for all traits, including earliness, fruit size, yield components, and quality traits (TSS, dry matter, and ascorbic acid). GCA and SCA effects were significant for all traits except dry matter content, indicating that both additive and dominance gene actions contribute to trait inheritance. The GCA:SCA ratios were greater than unity for most traits, indicating the predominance of additive gene action, suggesting that pure-line breeding would be effective for improvement. Parental evaluation revealed distinct contributions to earliness, fruit size, yield components, and quality traits. BG-01 and BG-16 were good general combiners for earliness traits, while BG-53 and BG-16 excelled for yield per plant and key components, including fruit weight and number of fruits per plant.

The evaluation of the six parents revealed distinct contributions to earliness, fruit size, key yield components, and quality traits. The parents, based on GCA effects for eleven traits, indicated that no single parent was a good general combiner for all characters. BG-01 and BG-16 were identified as good general combiners for earliness, while parents BG-53, BG-16, and BG-21 showed good general combining ability for yield-related traits. Thus, BG-53, BG-16, and BG-21 were superior general combiners for fruit yield per plant and its key components, including fruit weight and number of fruits per plant. In addition, BG-01, BG-53, and BG-21 for fruit length and BG-55 and BG-53 for quality traits. BG-53 consistently showed significant positive GCA effects for fruit length, fruit weight, number of fruits, TSS, and ascorbic acid, indicating strong potential for enhancing overall yield. BG-21 contributed positively to fruit length but to a lesser extent. In addition, BG-21 also showed significant positive GCA effects for fruit length, though with lower magnitudes than BG-53, suggesting its moderate contribution toward yield improvement. The parents with strong GCA for yield also tended to have good GCA for yield-contributing traits. High GCA effects reflected superior parental performance and effective transmission of genetic effects to progenies, while low GCA indicated limited divergence from the cross

mean. All parents showed appreciable combining ability for various quality traits, supporting their use in hybrid development.

Analysis of specific combining ability (SCA) and reciprocal effects indicated the role of non-additive gene action, maternal effects, and cross direction in the inheritance of earliness, yield, and quality traits under heat stress. Significant and desirable negative SCA effects for earliness traits were observed in crosses such as BG-01×BG-21, BG-21×BG-55, BG-16×BG-42, and BG-21×BG-42, showing consistently early flowering and fruit harvest. These SCA effects occurred across good × good, good × poor, and poor × poor parental combinations, indicating that earliness was largely influenced by non-additive gene action with some additive effects. For fruit size, crosses BG-16×BG-53, BG-01×BG-53, BG-01×BG-21, and BG-53×BG-55 showed significant positive SCA for fruit length, while BG-42×BG-55, BG-21×BG-53, and BG-01×BG-53 were superior for fruit diameter, demonstrating the importance of non-additive gene action and indicating heterosis exploitation in market preference fruit size improvement.

For yield and key components such as number of fruits, fruit weight, and yield per plant, strong positive SCA was shown in crosses BG-16×BG-53, BG-42×BG-55, BG-21×BG-53, BG-01×BG-53, and BG-01×BG-21. Superior hybrids arose not only from good × good GCA parents but also from good × poor and poor × poor combinations, indicating the predominance of non-additive effects and the potential for heterosis-based hybrid development. Quality traits (TSS, dry matter, and ascorbic acid) exhibited both positive and negative SCA effects, indicating complex genetic inheritance involving additive and non-additive gene actions. Among the crosses, BG-42 × BG-53, BG-53 × BG-55, BG-01 × BG-21, and BG-21 × BG-55 were identified as potential cross combinations for quality improvement in bottle gourd under heat stress conditions.

The reciprocal effects revealed significant maternal and cytoplasmic influences on most traits studied. Reciprocal combining ability analysis under heat stress identified superior cross combinations BG-21 × BG-01, BG-21 × BG-16, BG-53 × BG-01, and BG-42 × BG-21 for earliness, fruit size, yield components, and quality traits. These results underscore the critical importance of cross direction in trait expression, particularly under summer heat stress conditions in bottle gourd.

5.4.2 Estimation of heterosis and selection of heterotic hybrids

A detailed evaluation of individual crosses revealed that only a few hybrids consistently expressed high and desirable heterosis across multiple traits and criteria (mid-parent, better parent, and standard heterosis over Moyna, Diana, and Sultan), indicating superior breeding value under heat stress. Most promising hybrids exhibited significant desirable negative heterosis for days to first female flower and days to first edible harvest, reflecting accelerated reproductive development. Notably, BG-01 × BG-21 recorded the earliest and strongest negative heterobeltosis for days to first harvest (−13.94%) and high negative standard heterosis over Diana (−16.08%). BG-53 × BG-01 and BG-21 × BG-53 also flowered early with reduced node numbers, making them suitable for short-duration cultivation under heat stress. These results highlighted the importance of non-additive gene action in controlling earliness.

Substantial heterosis was observed for fruit size traits. BG-53 × BG-16 showed exceptionally high heterosis for fruit length (46.21% over mid-parent and 33.33% over better parent), indicating superiority for elongated fruit type. BG-53 × BG-01 and BG-01 × BG-21 also exhibited marked improvements in fruit length. For fruit diameter, hybrids involving BG-42 and BG-55 were superior, particularly BG-42 × BG-55, which was expressed very high standard heterosis over all checks.

Yield and its components displayed the highest magnitude of heterosis. BG-53 × BG-16 recorded the highest heterosis for number of fruits per plant (56.25% over mid-parent and 47.27% over better parent) and yield per plant (78.78% mid-parent heterosis and 84.73% standard heterosis over Diana). BG-53 × BG-01 demonstrated the highest gains in fruit weight, with an estimated 24.84% mid-parent heterosis and 21.79% heterobeltosis, along with a significant standard heterosis of 31.03% compared to Sultan. BG-53 × BG-01 demonstrated significant heterosis for yield, with increases of 47.22% over the mid-parent and 41.27% over the better parent. It also recorded the highest gains in fruit weight, exhibiting 24.84% mid-parent heterosis, 21.79% heterobeltosis, and a significant standard heterosis of 31.03% over Sultan. Additionally, BG-01 × BG-21, BG-21 × BG-53, and BG-55 × BG-42 consistently expressed positive heterosis for fruit number and yield across standard checks, indicating the predominance of dominance and over-dominance effects and identifying these crosses as elite yielders under heat stress.

Quality traits such as total soluble solids (TSS), dry matter content, and ascorbic acid also exhibited significant heterosis. BG-53 × BG-55 showed the highest heterosis for TSS (66.08% over mid-parent and 50.68% heterobeltosis), suggesting enhanced sweetness. BG-01 × BG-21 combined strong yield performance with substantial TSS improvement. Hybrids BG-01 × BG-55 and BG-53 × BG-55 excelled in dry matter content, while BG-55 × BG-21 recorded the highest heterosis for ascorbic acid, followed by BG-01 × BG-21. These results demonstrated that heterosis breeding can be effectively integrated with yield improvement to enhance nutritional quality under heat stress conditions.

Conclusion

The present study revealed wide genetic variability among bottle gourd genotypes under both optimum and heat stress conditions, indicating substantial potential for genetic improvement. High heritability coupled with considerable genetic advance for key traits suggests strong scope for effective selection. The results identified number of fruits per plant, fruit weight, and fruit diameter as the most reliable selection criteria for yield improvement under both environments. Earliness traits, particularly early female flowering and early fruit harvest indirectly enhanced yield through increased fruit number. Therefore, breeding strategies targeting early flowering, higher fruit number, and greater fruit weight would be effective for developing high-yielding and heat-tolerant genotypes under rising temperature conditions.

Heat stress tolerance analysis of 58 genotypes demonstrated considerable reductions in fruit diameter (40.63%), number of fruits per plant (48.73%), fruit weight (45.13%), and yield per plant (55.35%) under summer heat stress, indicating the detrimental impact of high temperature on productivity. The stress tolerance indices and their rankings effectively differentiated genotypes into tolerant and susceptible groups under summer heat stress conditions. The correlation coefficient analysis of heat stress indices revealed that MP, GMP, HM, STI, and TOL had highly positive correlations with Yp and Ys, but TOL and SSI had negative associations with Ys. Thus, these indices can be utilized for identifying heat-tolerant bottle gourd genotypes. PCA analysis revealed 98.39% of total genetic variation employed in PC1 and PC2 were classified genotypes as tolerant and susceptible, respectively. Cluster analysis depicted genotypes more clearly for tolerant, mid-tolerant, and susceptible groups for heat stress environments. Based on the contribution of indices through the PCA, biplot, and ranking method, genotypes BG-45, BG-02, BG-57, BG-39, and BG-43 were identified as heat-tolerant genotypes. Further, the

heat tolerance indices TOL, SSI, MP, GMP, STI, and YI were the most effective indicators for screening heat tolerance genotypes.

Line × tester analysis indicated the predominance of additive gene action for yield and its components, along with contributions of non-additive effects. The combined evaluation of mean performance and general combining ability (GCA) effectively identified superior parents in bottle gourd, with BG-01, BG-16, and BG-21 as good general combiners and BG-42, BG-55, and BG-53 showing moderate and trait-specific potential. These parents offer a diverse genetic base for future hybridization in the diallel crossing program.

The 6 × 6 full diallel analysis further confirmed significant GCA and SCA variances for all studied traits, indicating the involvement of both additive and dominance gene effects. The GCA:SCA ratios greater than unity for most traits emphasized the importance of additive gene action, suggesting that selection-based breeding approaches would be effective for the improvement of these traits. None of the parents consistently exhibited good general combining ability for all studied traits. However, BG-53, BG-16, and BG-21 were strong combiners for yield and its components; BG-01 and BG-16 were superior for earliness, BG-01, BG-53, and BG-21 for fruit length, and BG-55 and BG-53 for quality traits. High SCA effects were observed in crosses BG-01 × BG-21, BG-01 × BG-53, BG-16 × BG-53, BG-21 × BG-53, and BG-42 × BG-55. Significant reciprocal effects in BG-21 × BG-01, BG-21 × BG-16, BG-55 × BG-42, and BG-55 × BG-21 highlighted the importance of maternal and cytoplasmic influences and the role of cross direction in hybrid development. Thus, BG-53, BG-16, and BG-21 were the most suitable parents for developing high-yielding bottle gourd hybrids. Heterosis analysis demonstrated that specific hybrids excelled for distinct breeding objectives. BG-53 × BG-16 and BG-53 × BG-01 performed exceptionally well for yield and fruit size, whereas BG-53 × BG-55 and BG-55 × BG-21 were distinguished by superior quality attributes. BG-01 × BG-21 showed superiority for earliness and quality traits. The consistent involvement of BG-53 and BG-21 in most high-performing hybrids establishes them as key parents for heterosis breeding under heat stress. Thus, BG-53 and BG-21 emerged as key parents, contributing to most high-performing heat-tolerant heterotic hybrids. Hybrids such as BG-53 × BG-16, BG-53 × BG-01, BG-01 × BG-21, BG-55 × BG-42, and BG-21 × BG-53 combined earliness, desirable fruit size, high yield, and acceptable quality, making them promising candidates for multilocation evaluation and potential commercial hybrid development under heat stress conditions.

CHAPTER VI
REFERENCES

Abhishek VR, Kumar J, Tomar S. (2020) Correlation and path analysis in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Plant Arch.* **20**(2):496–99.

Achigan-Dako EG, Fuchs J, Ahanchede A, Blattner FR. (2008) Flow cytometric analysis in *Lagenaria siceraria* (Cucurbitaceae) indicates correlation of genome size with usage types and growing elevation. *Plant Syst Evol.* **276**(1):9–19.

Achu MB, Fokou E, Tchiégang C, Fotso M, Tchouanguep FM. (2005) Nutritive value of some Cucurbitaceae oilseeds from different regions in Cameroon. *Afr J Biotechnol.* **4(**11):1329–34.

Adarsh A, Kumar R, Kumar A, Chaurasiya J, Singh HK, Roy C. (2015) Combining ability analysis in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] for earliness and fruit yield. *Green Farming.* **6**(5):988–90.

Ahmad M, Singh B, Prakash S, Kumar V, Gupta S, Gangwar LK, and Alam K. (2022) Estimation of combining ability for yield and yield components traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Pharma Innov. J.* **11**(7): 3498-501

Akhond MAY, Rahman MA, Ahmed AU, Ahmad AU, Rashid MA, Rahman MHH. (2025) *Krishi Projukti Hatboi (Handbook on Agro-Technology*). 10th ed. Bangladesh Agricultural Research Institute (BARI); pp. 205–207.

Allard RW. (1960) Genetic basis of inbreeding depression and heterosis. In *Principles of Plant Breeding*. John Wiley and Sons, Inc., New York, p. 224-32.

Anwar J, Subhani GM, Hussain M, Ahmad J, Hussain M, Munir M. (2011) Drought tolerance indices and their correlation with yield in exotic wheat genotypes. *Pak. J. Bot.* **43**(3):1527-30.

Arunachalam V. (1991) Genetic distances in plant breeding. *Indian J Genet Plant Breed.* **41**:226–37.

Baker RJ. (1978) Issues in diallel analysis. *Crop Sci.* **18**:533–36.

Balat JR, Patel JB, Delvadiya IR, Joshiyara NS. (2020) Heterosis for fruit yield and its components in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *J Pharmacogn Phytochem.* **9**(5):226–33.

Bangladesh Bureau of Statistics (BBS). (2024) *Yearbook of Agricultural Statistics–2024.* 36th series. Dhaka: Statistics and Informatics Division (SID), Ministry of Planning; p. 320.

Bashir K, Masoodi UH, Ali G, Nazir N, Malik AR, Nazir G, Aftab O. (2024) Genetic variability, correlation, and path coefficient analysis in bottle gourd genotypes. *J Sci Res Rep.* **30**(5):760–71.

Basavaraj PS, Muralidhara B, Manoj CA, Anantha MS, Rathod S, Raju CD, Senguttuvel P, Madhav MS, Srinivasaprasad M, Prakasam V, Basavaraj K. (2021) Identification and molecular characterization of high-yielding, blast resistant lines derived from *Oryza rufipogon* Griff. in the background of 'Samba Mahsuri' rice. *Genet Resour Crop Evol.* **68**(5):1905–21.

Bhaiya R, Yadav GC. (2022) Combining Ability Analysis for Fruit Yield in Bottle Gourd [Lagenaria siceraria (Mol.) Standl]. *Int. J. Plant Soil Sci.* **34**(23):905-11.

Bhalala KC, Acharya RR. (2019) Assessment of combining ability using line × tester analysis over environments in tomato (*Solanum lycopersicum* L.). *J Pharmacogn Phytochem.* **8**(3):4478–85.

Bhatt R, Raghav M, Bisht YS, Kumar V, Chauhan A, Gaur A. (2023) Heterosis and combining ability for nutritional quality in bottle gourd (*Lagenaria siceraria*). *Indian J Agric Sci.* **93**(11):1197–201.

Bidinger FR, Mahalakshmi V, Rao GD. (1987) Assessment of drought resistance in pearl millet [*Pennisetum americanum* (L.) Leeke]. I. Factors affecting yields under stress. *Aust J Agric Res.* **38**(1):37–48.

Bita C, Gerats T. (2013) Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Front Plant Sci.* **4**:273.

Blum A. (1988) *Plant breeding for stress environments.* Boca Raton (FL): CRC Press.

Bose TK, Som MG. (1986) *Vegetable crops in India.* Naya Prokash, Calcutta p. 91–164.

Bouslama M, Schapaugh WT. (1984) Stress tolerance in soybean. Part 1: Evaluation of three screening techniques for heat and drought tolerance. *Crop Sci.* **24**:933–37.

Bulmer G. (1980) *The mathematical theory of quantitative genetics.* Oxford: Clarendon Press.

Burow MD, Coors JG. (1993) Diallel analysis and simulation. Wisconsin: University of Wisconsin.

Burton GW. (1952) Quantitative inheritance in grasses. In: *Proc 6th Int Grassl Congr.* **1**:277–83.

Camejo D, Rodríguez P, Morales MA, Dell'Amico JM, Torrecillas A, Alarcón JJ. (2005) High temperature effects on photosynthetic activity of two tomato cultivars with different heat susceptibility. *J Plant Physiol.* **162**(3):281–9.

Chowdhury AKMKA. (2021) *Selection of parents for hybrid variety development in tomato (Solanum lycopersicum L.).* PhD thesis. Department of Genetics and Plant Breeding. Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh.

Christie BR, Shattuck VI. (2010) The diallel cross: design and analysis. *Plant Breed Rev.* **9**:9–36.

Comstock RE, Robinson HF. (1952) Genetic parameters, their estimation and significance. In: *Proc 6th Int Grassl Congr.* **1**:284–91.

Cole MB, Augustin MA, Robertson MJ, Manners JM. (2018) The science of food security. *npj Sci Food.* **2**(1):14.

Cruz CD, Regazzi AJ. (1997) *Modelos biométricos aplicados ao melhoramento genético.* 2nd ed. Brazil: Editora UFV; p. 390.

Deepthi B, Reddy PSS, Kumar AS, Reddy AR. (2016) Character association and path coefficient analysis in bottle gourd (*Lagenaria siceraria* Mol.) genotypes. *Plant Arch.* **16**(2):531–36.

Dabholkar AR. (1992) *Elements of biometrical genetics.* New Delhi: Concept Publishing Company.

Devi K, Chahal S, Singh S, Venkatesh K, Mamrutha HM, Raghav N, Singh G, Singh GP, Tiwari R. (2021) Assessment of wheat genotypes based on various indices under different heat stress conditions. *Indian J Genet Plant Breed.* **81**(3):376–82.

Dewey DR, Lu KH. (1959) A correlation and path-coefficient analysis of components of crested wheatgrass seed production. *Agron J.* **51**(9):515–18.

Dey SS, Behera TK, Munshi AD, Rakshit S, Bhatia R. (2012) Utility of gynoecious sex form in heterosis breeding of bitter gourd and genetics of associated vegetative and flowering traits. *Indian J Hortic.* **69**(4):523-29.

Dodig D, Zoric M, Knezevic D, King SR, Surlan-Momirovic G. (2008) Genotype× environment interaction for wheat yield in different drought stress conditions and agronomic traits suitable for selection. *Aust J Agric Res.* **59**(6):536-45.

Doloi N, Patel JN, Patel NJ. (2017) Heterosis for fruit yield and its component traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Veg Sci.* **44**(2):107–9.

Doloi N, Patel JN, Acharya RR. (2018) Heterosis studies in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Scitechnol J.* **31**(1):1–3.

Dubey SK, Maurya IB. (2006) Combining ability studies in bottle gourd [*Lagenaria siceraria* (L.) (Molina) Standl.]. *Indian J Hortic*. **63**(2):178-181.

Dubey RK, Ram HH. (2008) Heterosis breeding in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Haryana J Hortic Sci.* **37**(1–2):126–7.

Duhan DS, Gill V, Panghal VPS, Karande PJ. (2022) Studies on genetic variability, heritability, genetic advance, and character association for quantitative traits in bottle gourd. *Veg Sci.* **49**(2):204–10.

East EM, Hayes HK. (1912) Heterosis in evolution and in plant breeding. *USDA Bull.* 243.

Ehlers JD, Hall AE. (1998) Heat tolerance of contrasting cowpea lines in short and long days. *Field Crops Res.* **55**:11–21.

Ergin S, Aydogan C, Turhan E. (2021) Physiological effects of high temperature stress in some cucurbit plants. *Curr Trends Nat Sci.* **10**(19):235–45.

Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, Sadia S, Nasim W, Adkins S, Saud S, Ihsan MZ. (2017) Crop production under drought and heat stress: plant responses and management options. *Front Plant Sci.* **8**:1147.

Farshadfar E, Poursiahbidi MM, Safavi SM. (2013) Assessment of drought tolerance in landraces of bread wheat based on resistance/tolerance indices. *Int J Adv Biol Biomed Res.* **1**(2):143–58.

Farshadfar E, Elyasi P. (2012) Screening quantitative indicators of drought tolerance in bread wheat (*Triticum aestivum*) landraces. *Eur J Exp Biol.* 2(3): 577-84.

Farshadfar E, Javadinia J. (2011) Evaluation of chickpea (*Cicer arietinum* L.) genotypes for drought tolerance. Seed Plant Improv. J. **27**(4), 517–37.

Fernandez GCJ. (1992) Effective selection criteria for assessing plant stress tolerance. In: Kuo CG, editor. *Proc Int Symp Adaptation Vegetables Other Food Crops in Temperature Water Stress.* Taiwan: Asian Vegetable Research and Development Center; p. 257–70.

Fischer RA, Maurer R. (1978) Drought resistance in spring wheat cultivars. I. Grain yield responses. *Aust J Agric Res.* **29**:897–912.

Fischer RA, Wood JT. (1979) Drought resistance in spring wheat cultivars. III. Yield associations with morpho-physiological traits. *Aust J Agric Res.* **30**(6):1001–20.

Fonseca A, Patterson F. (1968) Hybrid vigour in a seven parent diallel cross in common winter wheat (*Triticum aestivum* L.). *Crop Sci.* **8**:85–8.

Gardner CO, Eberhart SA. (1966) Analysis and interpretation of the variety cross diallel and related populations. *Biometrics.* **22**:439–52.

Gautam DK, Yadav GC, Kumar P, Kumar V, Singh M. (2017) Estimation of heterosis for growth, yield, and quality traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Int J Curr Microbiol Appl Sci.* **6**(8):789–802.

Gavuzzi P, Rizza F, Palumbo M, Campanile RG, Ricciardi GL, Borghi B. (1997) Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Can J Plant Sci.* **77**(4):523–31.

Ghorpade SB, Jagtap VS, Ban SJ, Chaudhari SP. (2019) Genetic variability studies for qualitative attributes in bottle gourd (*Lagenaria siceraria* L.). *J Pharmacogn Phytochem.* **8**(5): 1911–13.

Ghosh H, Das A. (2003) Optimal diallel cross designs for estimation of heritability. *J Stat Plan Inference.* **116**(1):185–96.

Ghuge MB, Syamal MM, Karcho S. (2016) Heterosis in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Indian J Agric Res.* **50**(5):466–70.

Ghule BV, Ghanti MH, Yeole PG, Saoji AN. (2007) Diuretic activity of *Lagenaria siceraria* fruit extracts in rats. *Indian J Pharm Sci.* **69**:817–19.

Grafius JE. (1959) Heterosis in barley. *Agron J.* **51:**551– 54.

Griffing B. (1956 a) Concept of general combining ability and specific combining ability in relation to diallel crossing systems. *Aust J Biol Sci.* **9**:463–93.

Griffing B. (1956 b) A generalized treatment of the use of diallel crosses in quantitative inheritance. *Heredity.* **10**:31–50.

Gull M, Sofi PA, Mir RR, Ara A, Zargar S. (2019) Productivity and resilience-based indices for identification of water stress resilient genotypes in cowpea (*Vigna unguiculata* L.). *Indian J Agric Res.* **53**(4):391–97.

Gurcan K, Say A, Yesitir H. (2015) A study of genetic diversity in bottle gourd [*Lagenaria siceraria* (Molina) Standl.] population and implications for the historical origins of bottle gourds in Turkey. *Genet Resour Crop Evol.* **62**:321–33.

Hadiya AM, Dhaduk LK, Vyas UM, Kelaiya DS, Maheta DR. (2020) Combining ability analysis over environments for fruit yield per vine and its components in bottle gourd [*Lagenaria siceraria* (Mol) Standl.]. *J Pharmacogn Phytochem.* **9**(5):631-4.

Hallauer AR, Miranda JB. (1982) *Quantitative genetics in maize breeding.* Ames (IA): Iowa State University Press; p. 432–80.

Hallauer AR, Russell WA, Lamkey KR. (1988) Corn breeding. In: Sprague GF, Dudley JW, editors. *Corn and corn improvement.* 3rd ed. Madison (WI): ASA; p. 463-64.

Hallauer AR, Carena MJ, Miranda Filho JD. (2010) Quantitative genetics in maize breeding. Springer Science & Business Media.

Haq SU, Khan A, Ali M, Khattak AM, Gai WX, Zhang HX, Wei AM, Gong ZH. (2019) Heat shock proteins: dynamic biomolecules to counter plant biotic and abiotic stresses. *Int J Mol Sci.* **20**(21):5321.

Harika M, Gasti VD, Shantappa T, Mulge R, Shirol AM, Mastiholi AB, Kulkarni MS. (2012) Evaluation of bottle gourd genotypes [*Lagenaria siceraria* (Mol.) Standl.] for various horticultural characters. *Karnataka J Agric Sci.* **25**(2):241–44.

Hart TGB. (2011) The significance of African vegetables in ensuring food security for South Africa's rural poor. *Agric Hum Values.* **28**:321–33.

Hathcock BR, Daniel ME. (1973) Yield and yield components heterosis in Avena hybrids. *Crop Sci.* **13**:8–18.

Hayman BI. (1954) The analysis of variance of diallel tables. *Biometrics*. **10**:235-244.

Hayman BI, Mather K. (1955) The description of genic interactions in continuous variation. *Biometrics.* **11**:31–50.

Hegde SG, Duhan DS, Sudesh, Nayana KR. (2024) Genetic variability, correlation, and path analysis in F_3 and F_4 generation of bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *J Adv Biol Biotechnol.* **27**(7):1028–41.

Husna A, Mahmud F, Islam MR, Mahmud MAA, Ratna M. (2011) Genetic variability, correlation, and path coefficient analysis in bottle gourd (*Lagenaria siceraria* L.). *Adv Biol Res.* **5**(6):323–27.

Iftekheddaula KM. (2003) *Genetic analysis of morpho-physiological characters in diallel cross of rice.* MSc thesis, Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Intergovernmental Panel on Climate Change (IPCC). (2014) *Climate change 2013: The physical science basis.* Fifth assessment report. Cambridge: Cambridge University Press.

Iqbal M, Usman K, Arif M, Jatoi SA, Munir M, Khan I. (2019) Evaluation of bottle gourd genotypes for yield and quality traits. *Sarhad J Agric.* **35**(1):27–35.

International Rice Research Institute (IRRI). (2014) *PBTools, version 1.4*. Los Baños (PH): Biometrics and Breeding Informatics, PBGB Division, IRRI.

Islam MR, Hossain MS, Bhuiyan MSR, Husna A, Syed MA. (2009) Genetic variability and path-coefficient analysis of bitter gourd (*Momordica charantia* L.). *Int J Sustain Agric*. **1**(3):53–7.

Islam SMR. (2017) Genetic estimates of bottle gourd (Lagenaria siceraria) genotypes for selecting promising parents to develop heterotic hybrids. PhD dissertation. Mymensingh (BD): Bangladesh Agricultural University, Department of Genetics and Plant Breeding.

Jahan MA, Hossain A, Timsina J, da Silva JA. (2018) Evaluation of tolerance of six irrigated spring wheat (Triticum aestivum L.) genotypes to heat stress using stress tolerance indices and correlation analysis. *Int J Agric Res*.**13**:39-52.

Janaranjani KG, Kanthaswamy VS, Kumar R. (2016) Heterosis, combining ability, and character association in bottle gourd for yield attributes. *Int J Veg Sci*. **22**(5):490–515.

Janaranjani KG, Kanthaswamy V. (2015) Correlation studies and path analysis in bottle gourd. *J Hort*. **2**(1):1–4.

Jayanth S, Lal M, Duhan DS, Vidya R. (2019) Estimation of heterosis and combining ability for earliness and vegetative traits in bottle gourd [*Lagenaria siceraria* (Molina) Standl.]. *Int J Chem Stud.* **7**(1):20–5.

Jinks JL, Hayman BI. (1953) The analysis of diallel crosses. *Maize Genet Coop Newsl.* **27**:48–54.

Jinks JL, Jones RM. (1958) Estimation of the components of heterosis. *Genetics* **43**: 223-34.

Jha UC, Basu P, Shil S, Singh NP. (2016) Evaluation of drought tolerance selection indices in chickpea genotypes. *Int J Bio-Resour Stress Manage*. **7**(6):1244-48.

Jha UC, Jha R, Singh NR, Shil S, Kole PC. (2018) Heat tolerance indices and their role in selection of heat stress-tolerant chickpea (*Cicer arietinum*) genotypes. *Indian J Agric Sci*. **88**(2):260–7.

Johnson HW, Robinson HF, Comstock RE. (1955) Estimates of genetic and environmental variability in soybeans. *Agron. J*. **47**: 314-18.

Kalpana K, Kumar P, Kumar S. (2019) Correlation studies and path analysis in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Veg Sci.* **8**(1): 1554–56.

Kavitha S, Vanangamudi K, Renuka R. (2006) Advances in seed science and technology. In: *Quality seed production in vegetables.* **2**:491–92.

Kearsey MJ, Pooni HS. (1996) *The genetic analysis of quantitative traits.* London: Chapman & Hall.

Kenga R, Alabi SO, Gupta SC. (2004) Combining ability studies in tropical sorghum (*Sorghum bicolor* (L.) Moench). *Field Crops Res.* **88**(2–3):251–60.

Kempthorne O. (1957) *An introduction to genetic statistics.* New York: John Wiley & Sons; London: Chapman & Hall.

Keshari D, Singh DK. (2024) Estimation of combining ability effect for hybrid breeding in bottle gourd [*Lagenaria siceraria* (Molina) Standl.] using diallel mating design. *J Exp Agric Int.* **46**(9):376–84.

Khairwal IS, Rai KN, Andrew DJ, Harinarayana G. (1999) *Pearl millet breeding.* New Delhi: Oxford & IBH Publishing Co.

Khalili M, Naghavi MR, Aboughadareh AP, Talebzadeh SJ. (2012) Evaluating of drought stress tolerance based on selection indices in spring canola cultivars (Brassica napus L.). *J Agric Sci.* **4**(11):78-85.

Khan MM, Singh SP, Ram H, Singh VB, Mubeen. (2016) Genetic variability in bottle gourd for quantitative traits. *J Pharmacogn Phytochem.* **5**(4):412–14.

Khan AA, Kabir MR. (2014) Evaluation of spring wheat genotypes (*Triticum aestivum* L.) for heat stress tolerance using different stress tolerance indices. *Cercetari Agronomice in Moldova*. XLVII: **4**(160): 49–63

Khot RK. (2017) *Heterosis and combining ability studies in advanced lines of bottle gourd* [*Lagenaria siceraria* (Mol.) Standl.]. MSc thesis. Bagalkot (IN): University of Horticultural Sciences.

Khot RK, Evoor S, Shwetha A. (2021) Combining ability studies in the advanced lines of bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] for growth, earliness, and yield parameters. *Int J Chem Stud.* **9**(2):1118–22.

Kim TY, Ku H, Lee SY. (2020) Crop enhancement of cucumber plants under heat stress by shungite carbon. *Int J Mol Sci.* **21**(14):4858.

Koelreuter JG. (1763) *Method of plant breeding.* New York: McGraw Hill Book Co.

Kornegay JL, Temple SR. (1986) Inheritance and combining ability of leafhopper defense mechanism in common bean. *Crop Sci.* **26**:1153–58.

Kumar A, Yadav GC, Pandey V, Prasad R. (2014) Mean performance of parents and F_1s for earliness and marketable yield-related traits in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Ann Biol.* **30**:394–99.

Kumar R, Reddy KM. (2021) Impact of climate change on cucurbitaceous vegetables in relation to increasing temperature and drought. In: *Advances in research on vegetable production under a changing climate.* Cham: Springer; p. 175–95.

Kumar A, Singh B, Kumar M. (2011) Exploitation of hybrid vigor for yield in bottle gourd (*Lagenaria siceraria* (Molina) Standl.) using line × tester analysis. *Plant Res.* **24**(2):45–8.

Kumar D, Kumar V, Kumar A, Prakash S, Singh R. (2020a) Studies on genetic variability, heritability and genetic advance among quantitative and qualitative characters in bottle gourd (*Lagenaria siceraria). Int J Curr Microbiol Appl Sci.* Spec Issue-1**0**:617–21.

Kumar R, Singh CM, Arya M, Kumar R, Mishra SB, Singh UK, Paswan S. (2020b) Investigating stress indices to discriminate the physiologically efficient heat tolerant genotypes of mungbean [*Vigna radiata* (L.) Wilczek]. *Legume Res.* **43**(1):43–9.

Kumar R, Kumar R, Prasad BD, Solankey SS, Kumar J, Bamaniya BS. (2018) Genetic variation study using morphological and DNA marker-based genotyping in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Curr J Appl Sci Technol.* **31**(2):1–10.

Kumari K, Kant K, Kumar R. (2021) Correlation studies and path analysis in bottle gourd. *Pharma Innov J.* **10**(10):557–60.

Kunjam K, Sharma PK, Som I, Kumar B. (2019) Correlation studies and path analysis in bottle gourd [*Lagenaria siceraria* (Molina) Standl.]. *J Pharmacogn Phytochem.* **8**(1):1554–56.

Lamba K, Kumar M, Singh V, Chaudhary L, Sharma R, Yashveer S, Dalal MS. (2023) Heat stress tolerance indices for identification of heat tolerant wheat genotypes. *Sci Rep.* **13**(1):10842.

Latimer GW Jr, editor. (2023 a) *Official Methods of Analysis of AOAC INTERNATIONAL*. 22nd ed. Rockville (MD): AOAC International; 2023. Official Method 932.12. Solids (Soluble) in Fruits and Fruit Products—Refractometer Method.

Latimer GW Jr, editor. (2023 b) *Official Methods of Analysis of AOAC INTERNATIONAL*. 22nd ed. Rockville (MD): AOAC International; 2023. Official Method 925.10. Moisture in Fruits and Fruit Products.

Latimer GW Jr, editor. (2023 c) *Official Methods of Analysis of AOAC INTERNATIONAL*. 22nd ed. Rockville (MD): AOAC International; 2023. Official Method 967.21. Ascorbic Acid in Vitamin Preparations and Juices—2,6-Dichloroindophenol Titrimetric Method.

LeGouis J, Beghin D, Heumez E, Plauchard P. (2002) Diallel analysis of winter wheat at two nitrogen levels. *Crop Sci.* **42**:1129–34.

Lesk C, Rowhani P, Ramankutty N. (2016) Influence of extreme weather disasters on global crop production. *Nature.* **529**(7584):84–7.

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL. (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science.* **319**:607–10.

Longin CF, Gowda M, Mühleisen J, Ebmeyer E, Kazman E, Schachschneider R, Schacht J, Kirchhoff M, Zhao Y, Reif JC. (2013) Hybrid wheat: quantitative genetic parameters and consequences for the design of breeding programs. *Theor Appl Genet.* **126**(11):2791–801.

Mahajan S, Tuteja N. (2005) Cold, salinity and drought stresses: an overview. *Arch Biochem Biophys.* **444**(2):139–58.

Mahapatra S, Sureja AK, Behera TK, Bhardwaj R. (2019) Correlation and path coefficient analyses of quantitative traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] genotypes. *Int J Chem Stud.* **7**(3):827–30.

Mahawar AK, Soni AK, Bairwa LN, Bairwa SK. (2021) Combining ability analysis in *Lagenaria siceraria*for growth and yield attributes. *Pharma Innov J.* **10**(8):1777–83.

Mashilo J. (2016) *Pre-breeding of bottle gourd (Lagenaria siceraria* (Molina) Standl.*).* PhD thesis. Department of Crop Science University of KwaZulu-Natal, Pietermaritzburg.

Mashilo J, Shimelis H, Odindo A. (2016) Correlation and path coefficient analyses of qualitative and quantitative traits in selected bottle gourd landraces. *Acta Agric Scand B Soil Plant Sci.* **66**(7):558–69.

Mashilo J, Shimelis H, Odindo A. (2017) Yield-based selection indices for drought tolerance evaluation in selected bottle gourd [*Lagenaria siceraria* (Molina) Standl.] landraces. *Acta Agric Scand B Soil Plant Sci.* **67**(1):43–50.

Masud MAT, Azam MG, Hasan MZ, Rashid AH, Bagum SA, Uddin MS. (2021) Heterosis and combining ability for yield and yield contributing characters in bottle gourd. *J Glob Agric Ecol.* **11**(4):13–20.

Mather K, Jinks JL. (1971) *Biometrical genetics: the study of continuous variation*. 2nd ed. London: Chapman and Hall Ltd.

Maurya IB, Singh SP, Singh NK. (1993) Heterosis and combining ability in bottle gourd [*Lagenaria siceraria* (Molina) Standl.]. *Veg Sci.* **20**:77–81.

Maurya SK, Ram HH, Singh DK. (2004) Combining ability analysis in bottle gourd. *Prog Hort.* **36**(1):67–72.

Meena RP, Tripathi SC, Chander S, Chookar RS, Verma MA, Sharma RK. (2015) Identifying drought-tolerant wheat varieties using different indices. *SAARC J Agric*. **13**(1):148–61.

Milind P, Satbir K. (2011) Is bottle gourd a natural guard? *Int Res J Pharm.* **2**:13–7.

Miller PA, Williams JC, Robinson HF, Comstock RF. (1958) Estimates of genotypic and environmental variances and covariances in upland cotton and their implication in selection. *Agron J.* **50**:126–31.

Mishra S, Pandey S, Kumar N, Pandey VP, Singh T. (2019) Studies on combining ability and gene action in kharif season bottle gourd [*Lagenaria siceraria* (Molina) Standl.]. *J Pharmacogn Phytochem.* **8**(1):11–18.

Mishra S, Pandey S, Kumar N, Pandey VP, Singh T. (2019) Studies on the extent of heterosis for quantitative characters in kharif season bottle gourd (*Lagenaria siceraria* (Molina) Standl.). *J Pharmacogn Phytochem.* **8**(1):29–38.

Mkhize P, Shimelis H, Mashilo J. (2023) Combining ability and heterosis among bottle gourd [*Lagenaria siceraria* (Molina) Standl.] selections for yield and related traits under drought-stressed and non-stressed conditions. *Diversity.* **15**(8):925.

Mohsin GM. (2015) *Genetic analysis of yield and yield contributing traits in pumpkin (Cucurbita moschata Duch. ex Poir).* PhD thesis. Department of Genetics and Plant Breeding Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh.

Morimoto Y, Gikungu M, Maundu P. (2004) Pollinators of the bottle gourd (*Lagenaria siceraria*) observed in Kenya. *Int J Trop Insect Sci.* **24**:79–86.

Muralidharan B, Kanthaswamy V, Janaranjani KG. (2017) Correlation and path analysis for quantitative and qualitative traits in bottle gourd [*Lagenaria siceraria* (Molina) Standl.]. *J Pharmacogn Phytochem.* **6**(5):2280–3.

Naghavi MR, Pour-Aboughadareh A, Khalili M. (2013) Evaluation of drought tolerance indices for screening some corn (*Zea mays* L.) cultivars under environmental conditions. *Not Sci Biol.* 5(3):388–93.

Nedi G, Tulu L, Alamerew S. (2017) Standard heterosis of selected maize (*Zea mays* L.) inbred line hybrids for grain yield and yield components at Jimma, Southwest Oromia Region, Ethiopia. *J Biol Agric Healthc.* **7**(5):51–8.

Ogunbusola M, Fagbemi T, Osundahunsi O. (2010) Amino acid composition of *Lagenaria siceraria* seed flour and protein fractions. *J Food Sci Technol.* **47**:656–61.

Olarewaju OO, Fajinmi OO, Arthur GD, Coopoosamy RM, Naidoo K. (2023) Effect of climate change on the production of Cucurbitaceae species in North African countries. *J Agric Food Res.* **14**:100742.

Pandey P, Dewedi D, Pandey M, Singh K. (2021) Genetic variability and correlation coefficient for horticultural traits in bottle gourd (*Lagenaria siceraria*). *Veg Sci.* **48**(1):111–13.

Panigrahi I, Duhan DS, Panghal VPS, Tehlan SK, Yadav AC. (2018) Correlation coefficient analysis between yield-defining traits of cultivated genotypes of bottle gourd (*Lagenaria siceraria*). *J Pharmacogn Phytochem.* 7(2):1378–1380.

Panse VG, Sukhatme PV. (1967) *Statistical methods for agricultural workers.* 2nd edn:, ICAR, New Delhi, 381.

Parmar SS, Pathak M. (2018) Combining ability and heterosis for yield and its contributing traits in bottle gourd (*Lagenaria siceraria*). *SKUAST J Res.* **20**(1):37–42.

Patel HR, Mehta DR. (2021) Elucidation of heterosis and inbreeding depression for fruit yield and its component traits in bottle gourd (*Lagenaria siceraria*). *Pharma Innov J.* **10**(6):646–54.

Patel P, Sharma RK, Bhardwaj A, Kumar R, Sahay S, Kumar A, Kumari R, Singh AB. (2023) Combining ability studies in bottle gourd (*Lagenaria siceraria*) for yield and its attributing traits during February season. *Biol Forum Int J.* **15**(1):367–72.

Porter JR. (2005) Rising temperatures are likely to reduce crop yields. *Nature.* **436**:174.

Porch TG. (2006) Application of stress indices for heat tolerance screening of common bean. *J Agron Crop Sci.* **192**:390–94.

Poudel RM, Dhakal A, Bhandari RK, Nyaupane S, Poudel S, Panthi B, Neupane P. (2024) Evaluation of wheat genotypes based on heat stress tolerance. *Ann Agri Bio Res.* **29**(1):50–56.

Pour-Aboughadareh A, Yousefian M, Moradkhani H, Moghaddam Vahed M, Poczai P, Siddique KHM. (2019) iPASTIC: An online toolkit to estimate plant abiotic stress indices. *Appl Plant Sci***. 7**(7): e11278.

Quamruzzaman AKM, Salim MMR, Akhter L, Rahman MM, Chowdhury MAZ. (2020) Combining ability study in some genetic stocks of bottle gourd. *Lond J Res Sci Nat Form.* **20**(2):93–102.

Quamruzzaman AKM, Salim MMR, Akhter L, Hasan T, Mazed K, Chowdhury MAZ. (2019) Genetic architecture of yield in bottle gourd (*Lagenaria siceraria*). *Agric Sci.* **10**:567–76.

Quick JS. (1978) Combining ability and interrelationship among an international array of durum wheat. In: Ramanujam S, editor. *Proc Fifth Int Wheat Genet Symp.* New Delhi. p. 634–647.

Rahaman MM, Hossain MK, Alam N. (2025) Estimation of combining ability and heterosis in bottle gourd. *Bangladesh J Bot.* **54**(3):601–609.

Rakesh KD, Ram HH. (2007) Genetics of seed yield and its components in bottle gourd (*Lagenaria siceraria*). *Cucurbit Genet Coop Rep*. **30**:64–70.

Rambabu E, Mandal AR, Hazra P, Senapati BK, Thapa U. (2017) Morphological characterization and genetic variability studies in bottle gourd (*Lagenaria siceraria*). *Int J Curr Microbiol Appl Sci***. 6**(9):3585–3592.

Rambabu E, Mandal AR, Das SP, Hazra P, Thapa U. (2021) Heterosis studies in bottle gourd [*Lagenaria siceraria* (Mol.) Standley.]. J Crop and Weed. **17**(2): 145-151.

Ramirez PV, Kelly JD. (1998) Traits related to drought resistance in common bean. *Euphytica.* **99**:127–136.

Ranganna S. (1986). *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*. 2nd ed. New Delhi: Tata McGraw-Hill Publishing Company.

Rathore S, Ola AL, Choudhary A, Bishnoi S. (2025) Inter-correlation and path coefficient analysis for agro-morphological and yield traits in bottle gourd (*Lagenaria siceraria*). *Curr Hort.* **13**(1):80–82.

Raut RL, Mishra SP. (2015) Combining ability studies in bottle gourd (*Lagenaria siceraria*). *Veg Sci.* **42**(1):63–66.

Ray PK, Yadav GC, Baranwal DK, Singh HK. (2015) Genetic estimates and gene action for obtaining promising heterotic hybrids in bottle gourd (*Lagenaria siceraria*). *Bioscan.* **10**(2):801–806.

Riggs TJ. (1988) Breeding F_1 hybrid varieties of vegetables. J Hortic Sci. **63**:362–369.

Rojas BA, Sprague GF. (1952) A comparison of variance components in corn yield trials: III. General and specific combining ability and their interaction with locations and years. *Agron J*.**44**:462-466.

Rosielle AA, Hamblin J. (1981) Theoretical aspects of selection for yield in stress and non-stress environments. *Crop Sci.* **21**:943–946.

Roy R, Agrawal V, Gupta SC. (2009) Comparison of drought-induced polypeptides and ion leakage in three tomato cultivars. *Biol Plant.* **53**(4):685–690.

Samadia DK. (2002) Performance of bottle gourd genotypes under hot arid environment. *Indian J Hort.* **59**(2):167–70.

Saroj PL, Choudhary BR. (2020) Improvement in cucurbits for drought and heat stress tolerance – a review. *Curr Hort.* **8**(2):3–13.

Saryam N, Tiwari A, Pandey S, Singh SK, Tiwari G. (2024) Estimation of heterosis and combining ability for quality traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *J Sci Res Rep.* **30**(10):70–77.

Seepal YS, Sharma V, Singh CM, Shukla G, Gangwar V, Kamaluddin, Singh SK. (2025) Application of stress indices to identify terminal heat tolerance genotype in field pea (Pisum sativum var. arvense). *Legume Res.* **48**(1):20–25.

Selvi NAT, Jansirani P, Pugalendhi L. (2015) Line × tester analysis for yield and its component traits in pumpkin (Cucurbita moschata Duch. ex Poir). *Electron J Plant Breed.* **6**(4):1004–10.

Seymen M, Dursun A, Yavuz D, Kurtar ES, Türkmen O. (2023) Identification of water stress-tolerant edible pumpkin seed (Cucurbita pepo) genotypes using seed yield-based tolerance indices. *Acta Sci Pol Hortorum Cultus.* **22**(4):67–78.

Shakoor U, Saboor A, Ali I, Mohsin AQ. (2011) Impact of climate change on agriculture: empirical evidence from arid region. *Pak J Agric Sci.* **48**(4):327–33.

Sharma A, Sengupta SK. (2012) Evaluation of genetic variability in bottle gourd genotypes. *Veg Sci.* **39**(1):83–85.

Sharma JR. (1998) Statistical and biometrical techniques in plant breeding. New Delhi: New Age International (P) Limited.

Sharma N, Sharma NK, Malik YS. (2002) Combining ability in long-fruited bottle gourd. Haryana *J Hortic Sci.* **31**(1/2):79–82.

Shinde S, Supe VS, Bhalekar MN, Gaikwad SS. (2016) Combining ability studies for earliness and yield in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.) in the kharif season. *Asian J Sci Technol.* **7**(5):2846–49.

Shukla PR, Skeg J, Buendia EC, Masson-Delmotte V, Pörtner HO, Roberts DC, *et al.* (2019) Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Geneva: IPCC.

Shull GH. (1948) What is heterosis? *Genetika*. **33**:430–46.

Singh RK, Chaudhary BD. (1985) Biometrical methods in quantitative genetic analysis. New Delhi: Kalyani Publishers. p.79–85.

Singh A, Singh D, Singh R, Jindal SK. (2022) Assessment of combining ability of watermelon germplasm derived from diverse geographic origin for yield and quality traits. *Genetika.* **54**(2):959–76.

Singh AK, Pan RS, Bhavana P. (2012) Correlation and path coefficient analysis for quantitative traits in early season bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Veg Sci.* **39**(2):198–200.

Singh BP, Singh RB, Pandey P, Kashyap N, Kumar S, Mishra A, *et al.* (2024) Studies on variability, heritability and genetic advance for yield and its contributing traits in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *Ecol Environ Conserv.* **30**(1):249–53.

Singh HK, Kumar R, Akhtar S, Adarsh A. (2017) Seasonal variation and genotypic variability studies on bottle gourd for yield and its attributing traits. *Int J Agric Environ Biotechnol.* **10**(3):357–66.

Singh VB, Singh SP. (2019) Study of heterosis for yield and its component traits in bottle gourd (Lagenaria siceraria Mol. Standl.). *J Pharmacogn Phytoc.* **8(**3):3678-81.

Singh M, Ameta KD, Kaushik RA, Dubey RB, Meena D, Meena R, *et al.* (2023) Estimation of combining ability in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Electron J Plant Breed.* **14**(2):758–62.

Singh R, Singh B, Prakash S, Kumar M, Kaushik H, Singh S, Kumar A. (2022) Correlation and path coefficient analysis in bottle gourd (*Lagenaria siceraria* L.). *Ecol Environ Conserv.* **28**(S):138–43.

Singh R, Singh B, Prakash S, Kumar M, Kumar A, Kumar M, *et al.* (2025) Assessment of combining ability and heterosis in bottle gourd (*Lagenaria siceraria* L.) for yield and attribute character through line × tester design. *Plant Sci Today.* **12**(1):1–8.

Singh SP. (2008) Bottle gourd breeding. *J New Seeds*. **6**:361–73.

Sirohi PS, Sivakami N. (1991) Genetic variability in cucurbits. *Indian J Hort.* **36**:44–45.

Sirohi S, Rana SC. (2008) Combining ability studies in bottle gourd. *Haryana J Hortic Sci.* **37**(3/4):309–11.

Smith SE, Doss AA, Warburton M. (1991) Morphological and agronomic variation in North African and Arabian alfalfas. *Crop Sci*. **31**:1159–63.

Snedecor GW, Cochran WG. (1989) Statistical methods. 8th ed. Ames: Iowa State University Press.

Spaldon S, Samnotra RK, Chopra S. (2015) Climate resilient technologies to meet the challenges in vegetable production. *Int J Curr Res Aca Rev.* **3**(2):28-47.

Sprague GF. (1966) Plant breeding. Ames (IA): Iowa State University Press.

Sprague GF, Tatum LA. (1942) General vs. specific combining ability in single crosses of corn. *J Am Soc Agron.* **34**:923–32.

Sree C, Talekar N, Janeja HS, Rohith K, Suryavanshi VD, Khan F. (2019) Correlation and path analysis for quantitative and qualitative traits in bottle gourd [*Lagenaria siceraria* (Molina) Standl.]. *Plant Cell Biotechnol Mol Biol.* **20**(7–8):324–30.

Sriom, Yadav G. (2021) Combining ability, variances, and their effects in bottle gourd (*Lagenaria siceraria* (Mol.) Standl.). *J Pharmacogn Phytochem*. **10**(1):2531–38.

Srivastava D, Khan NA, Shamim MD, Yadav P, Pandey P, Singh KN. (2014) Assessment of the genetic diversity in bottle gourd [*Lagenaria siceraria* (Molina) Standl.] genotypes using SDS-PAGE and RAPD markers. *Natl Acad Sci Lett.* **37**:155–61.

Sukhlecha A. (2012) Bitter bottle gourd (*Lagenaria siceraria*): healer or killer? *Int J Nutr Pharmacol Neurol Dis*. **2**:276–77.

Sultan B, Defrance D, Iizumi T. (2019) Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Sci Rep.* **9**:12834.

Sultana S, Rahman MS, Ferdous J, Ahamed F, Chowdhury AK. (2018) Studies on genetic variability and interrelationship in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Int J Agric Res Innov Technol.* **8**(1):14–17.

Sun Q, Miao C, Hanel M, Borthwick AG, Duan Q, Ji D, *et al.* (2019) Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming. *Environ Int.* **128:**125–36.

Suthanthirapandian IR. (1986) Studies on heterosis and combining ability in chili (*Capsicum annuum* L.) PhD dissertation. Tamil Nadu Agricultural University, Coimbatore, India.

Szymanska R, Slesak I, Orzechowska A, Kruk J. (2017) Physiological and biochemical responses to high light and temperature stress in plants. *Environ Exp Bot.* **139**:165–77.

Thakur P, Singh J, Nair SK, Dash SP. (2017) Correlation and path analysis in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Int J Curr Microbiol Appl Sci.* **6**(12):1478–1485.

Tiwari A, Ram HH. (2009) Inheritance of fruit shape in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Veg Sci*. **36**:147–149.

Tyagi ID. (1973) Heterosis in bottle gourd. *Indian J Hort.* **33**:393–400.

Tyagi ID. (1976) Inheritance of some qualitative characters in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Indian J Hort.* **33**:79–82.

Ullah A, Shakeel A, Ahmed HG, Naeem M, Ali M, Shah AN, Wang L, Jaremko M, Abdelsalam NR, Ghareeb RY, Hasan ME. (2022) Genetic basis and principal component analysis in cotton (*Gossypium hirsutum* L.) grown under water deficit condition. *Front Plant Sci.* **13**:981369.

Varalakshmi B, Pitchaimuthu M, Sreenivas Rao E. (2018) Genetic variability, correlation and path analysis in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] germplasm. *J Hortic Sci.* **13**(2):131–136.

Vegad PM, Vaddoria MA, Mehta DR, Naghera YV. (2011) Combining ability analysis in bottle gourd. *Crop Improv.* **38**:13–17.

Vekariya TA, Kulkarni GU, Vekaria DM, Dedaniya AP, Memon JT. (2019) Combining ability analysis for yield and its components in tomato (*Solanum lycopersicum* L.). *Acta Sci Agric.* **3**(7):185–191.

Venkatraman M, Haripriya K. (2021) Genetic variability, heritability, and genetic advance in bottle gourd [*Lagenaria siceraria* (Molina) Standl.] genotypes. *Ann Plant Soil Res.* **23**(2):200–203.

Wani KP, Ahmed N, Afroza B, Hussain K. (2009) Line × tester analysis for combining ability in bottle gourd under temperate conditions of Kashmir valley. *Indian J Hort.* **66**(4):476–482.

Waraich EA, Ahmad R, Ashraf MY, Saifullah, Ahmad M. (2011) Improving agricultural water use efficiency by nutrient management in crop plants. *Acta Agric Scand B Soil Plant Sci.* **61**(4):291–304.

Waraich EA, Ahmad R, Halim A, Aziz T. (2012) Alleviation of temperature stress by nutrient management in crop plants: a review. *J Plant Nutr Soil Sci.* ***12***(2):221–244.

Whitaker TW, Carter GF. (1961) A note on the longevity of seed of *Lagenaria siceraria* (Mol.) Standl. after floating in sea water. *Bull Torrey Bot Club*. **88**(1):104–106.

Wright S. (1921) Systems of mating. *Genetics*. **6**:111–178.

Yadav A, Yadav GC, Abha R, Kumar S, Yadav L, Bhaiya R. (2025) Estimation of combining ability and nature of gene action for yield and quality traits in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.] under salt affected soil. *Veg Sci.* **52**(1):112–121.

Yadav YC, Kumar S. (2012) Assessment of standard heterosis for crop advancement in bottle gourd [*Lagenaria siceraria* (Mol.) Standl.]. *Int J Plant Sci.* **7**(1):181–184.

Yan W, Kang MS. (2002) *GGE Biplot Analysis: A Graphical Tool for Breeders, Geneticists, and Agronomists.* 1st ed. Boca Raton (FL): CRC Press. 288 p.

Yücel D, Mart D. (2014) Drought tolerance in chickpea (*Cicer arietinum* L.) genotypes. *Turk J Agric Nat Sci.* **1**(Special Issue 1):1299–1303.

Zamir D. (2001) Improving plant breeding with exotic genetic libraries. *Nat Rev Genet.* **2**:983–989.

Zary KW. (1980) The genetics and heritability of quantitative differences in N_2 fixation in cowpea (*Vigna unguiculata* L.). PhD dissertation, Texas A&M University, College Station, USA.

Zhang X, Li X, Chen D, Cui H, Ge Q. (2019) Overestimated climate warming and climate variability due to spatially homogeneous CO_2 in climate modeling over the Northern Hemisphere since the mid-19th century. *Sci Rep*. **9:**17426.

Zhou H, Guo S, An Y, Shan X, Wang Y, Shu S, Sun J. (2016) Exogenous spermidine delays chlorophyll metabolism in cucumber leaves (*Cucumis sativus* L.) under high temperature stress. *Acta Physiol Plant.* **38:**224.

Zopluoglu C, Davenport EC (2017) A note on using eigenvalues in dimensionality assessment. *Pract Assess Res Eval.* **22**(7):1–10

APPENDICES

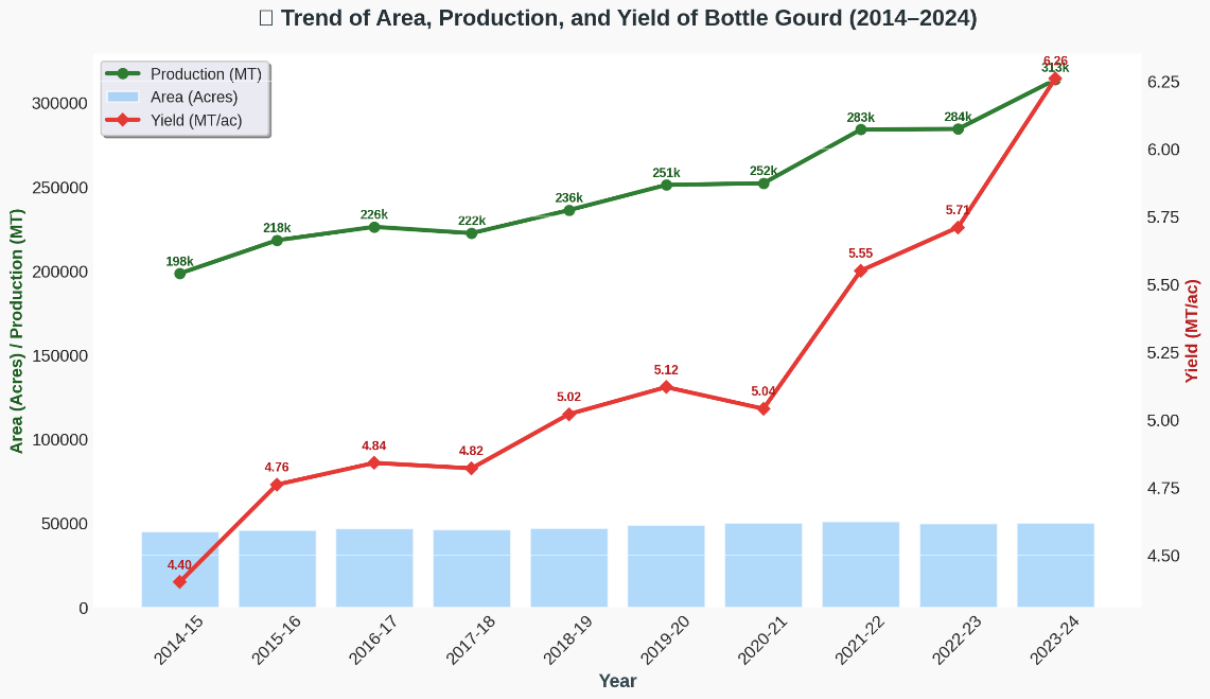
Appendix-I: Salient features of the experimental location

Items	Key Features
Physiographic unit	Old Himalayan Piedmont Plain (AEZ-1)
Geographic location	Northern Bangladesh (Dinajpur, Thakurgaon, Panchagarh,)
Origin	Deposits from Himalayan foothills
Topography	Gently undulating to nearly level
Soil texture	Sandy loam to clay loam
Soil reaction (pH)	Slightly acidic to neutral (≈5.5–6.8)
Soil fertility status	Moderate to low organic matter
Drainage condition	Well to moderately well drained
Major soil constraints	Low organic matter, occasional drought stress
Agricultural significance	Suitable for cereals, vegetables, and hybrid crop evaluation
Relevance to experiments	Uniform soils, low salinity, suitable for stress tolerance studies
Source: FAO, CIMMYT-Bangladesh	

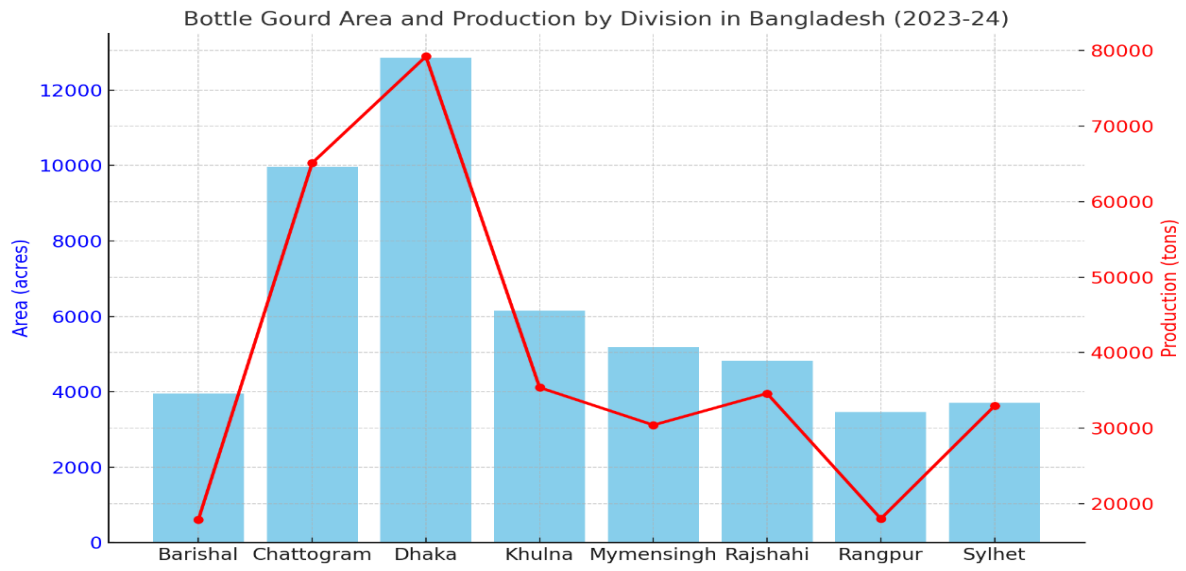
Appendix-II: Chemical properties and fertility status of the experimental soil

Soil parameter	Tested value	Fertility status
Nitrogen (N)	0.05 %	Very low
Phosphorus (P)	58.04 µg g^{-1}	Very high
Potassium (K)	0.16 meq 100 g^{-1}	Low–medium
Sulphur (S)	3.62 µg g^{-1}	Very low
Zinc (Zn)	4.13 µg g^{-1}	Very high
Boron (B)	0.59 µg g^{-1}	Adequate
Magnesium (Mg)	2.67 meq 100 g^{-1}	Adequate
Soil pH	5.72	Slightly acidic
Organic matter (OM)	1.02	Low
Source: Soil Resource Development Institute (SRDI), Nashipur, Dinajpur, Bangladesh		

Appendix-III: Ten (10) years bottle gourd area, production and yield trends in Bangladesh



Appendix IV: Division wise bottle gourd area (acres) and production (tons) in Bangladesh in 2023–24.



Appendix-V: Monthly weather parameters during the experimental seasons (Rabi 2022–23 and Kharif-1, 2023)

Name of Month	Max. Temp (°C)	Min. Temp (°C)	Relative Humidity (%)	Rainfall (mm/day)
A. Optimum season weather data during Rabi 2022-23				
October 2022	32.21	22.72	79.77	97
November 2022	30.22	16.70	77.03	0
December 2022	26.54	13.40	79.60	0
January 2023	23.46	10.34	81.50	0
Non-stress (average)	29.66	17.61	78.80	32.33
B. Heat stress condition weather data during Kharif-1, 2023				
April 2023	34.47	21.19	66.76	41
May 2023	34.70	23.24	74.33	74
June 2023	35.13	25.77	75.14	199
July 2023	34.16	27.22	81.17	344
Heat-stress (average)	34.62	24.36	74.35	164.50
Increase/decrease (+/-)	4.96	6.75	-4.45	132.17

Appendix-VI: Monthly weather parameters during the experimental seasons (Rabi 2023–24 and Kharif-1, 2024)

Month	Max Temp (°C)	Min Temp (°C)	Relative Humidity (%)	Total Rainfall (mm)
A. Hybridization stage				
October 2023	31.85	21.66	80.94	213
November 2023	30.87	17.35	77.37	0
December 2023	26.97	13.94	79.87	15
January 2024	21.41	10.18	86.81	0
February 2024	26.9	13.38	73.9	2
Hybridization (avg)	27.60	15.30	79.78	46.00
B. Evaluation stage at Heat stress condition				
April 2024	36.20	21.77	63.57	0
May 2024	34.10	23.38	73.48	120
June 2024	32.67	25.63	83.07	347
July 2024	34.35	27.48	80.39	428
Kharif (avg)	34.33	24.57	75.13	223.75
Kharif Vs Rabi	+6.73	+9.26	-4.65	+177.75

Appendix-VII: Monthly weather parameters during the experimental seasons (Rabi 2024–25 and Kharif-1, 2025)

Months	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Total Rainfall (mm)
A. Hybridization stage				
October 2024	32.18	20.96	83.94	213
November 2024	30.87	17.65	76.37	10
December 2024	25.97	13.86	81.87	0
January 2025	20.84	10.27	86.81	0
February 2025	27.3	13.51	73.9	0
Rabi 2024-25 (Avg)	27.43	15.25	80.58	44.60
B. Heat stress condition				
April 2025	36.7	22.13	63.57	0
May 2025	34.1	23.49	70.48	220
June 2025	32.98	26.23	84.07	347
July 2025	34.35	27.26	80.39	445
Aug 2025	33.85	27.01	82.39	385
Kharif Heat stress (Avg)	34.40	25.22	76.18	279.40
Kharif Vs Rabi	+6.96	+9.97	-4.40	+234.80

Appendix: VIII. Pictorial views of selected promising hybrids and their parents



Female parent (♀) BG-53



F_1 (♀ BG-53 × ♂ BG-16)



Male parent (♂) BG-16



Female parent (♀) BG-01



F_1 (♀ BG-01 × ♂ BG-21)



Male parent (♂) BG-21



Female parent (♀) BG-55



F_1 (♀ BG-55 × ♂ BG-42)



Male parent (♂) BG-42



Female parent (♀) BG-21



F_1 (♀ BG-21 × ♂ BG-53)



Male parent (♂) BG-53



Female parent (♀) BG-53



F_1 (♀ BG-53 × ♂ BG-01)



Male parent (♂) BG-01