HEAT TOLERANCE IN WHEAT UNDER LATE SEEDED CONDITIONS

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SRIPATI SIKDER

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HEAT TOLERANCE IN WHEAT UNDER LATE SEEDED CONDITIONS

SRIPATI SIKDER

Registration No. 97-05-586

Certificate of Approval

(Dr. Jalal Uddin Ahmed)
Major Professor and Chairman
Advisory Committee

(Dr. Tofazzal Hossain)
Member
Advisory Committee

(Dr. M.A. Khaleque Mian)
Member
Advisory Committee

(Dr. M. Mofazzal Hossain)
Member
Advisory Committee

THESIS ABSTRACT

HEAT TOLERANCE IN WHEAT UNDER LATE SEEDED CONDITIONS

BY

Sripati Sikder

In a field experiment ten recommended wheat varieties were exposed to two sowing conditions- eg. optimum sowing (November 30) and late sowing (December 30) during November 1997 to April 1998 at the research farm of the Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, Bangladesh. By late sowing the varieties were given high temperature treatment during reproduction growth phase in comparison to optimum sowing. The experiment was conducted to determine the relative heat tolerance of wheat varieties and to evaluate the relative performance of heat tolerant and heat sensitive varieties under late seeded conditions. Based on membrane thermostability (MT) test four varieties (eg. Ananda, Pavon, Aghrani and Barkat) took maximum heat killing time and were classified as relatively heat tolerant, three varieties (eg. Akbar, Kanchan and Protiva) as moderately tolerant and the rest three varieties (eg. Balaka, Sawgat and Sonora) took the shortest heat killing time and considered as heat sensitive. In November 30 sowing both tolerant and sensitive varieties had similar grain filling duration (40 days). But in December 30 sowing the tolerant variety had longer grain filling duration (32 days) compared to sensitive variety (28 days). In both sowing time heat tolerant variety had higher grain growth rate compared to sensitive variety. In December 30 sowing both the tolerant and moderately tolerant varieties showed lower pre-anthesis stem reserves contribution to the final grain weight compared to November 30. But the heat sensitive varieties had higher pre-anthesis stem reserves contribution at December 30 (late sowing) conditions. The grain number per ear, 1000 grain weight and main shoot grain weight of the tolerant and moderately tolerant varieties showed higher relative performance compared to sensitive varieties. But the relative ear number per plant and relative grain yield were found to range from low to high in heat tolerant and moderately tolerant varieties. In heat sensitive varieties the relative ear number per plant and relative grain yield were moderate to high. Thus the results suggest that in addition to membrane thermostability test, the long grain filling duration with high filling rate, less dependence on pre-anthesis stem reserves, high relative grain number per ear, 1000 grain weight and main shoot grain weight can be used to determine the heat tolerance of wheat varieties under late seeded warmer conditions.

TO MY LATE MOTHER

WHOSE ETERNAL MEMORY

INSPIRES ME .....

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CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important crop and ranks first globally among the cereals both in term of production and acerage (FAO, 1988). It is more nutritious than rice (Appendix 1). In Bangladesh wheat is the second most important cereal crop next to rice and in 1995-96 it occupied an area of 701.39 thousand hectares with a total production of 1369.13 thousand tons (BBS, 1997). The average wheat yield (2.0 t/ha) in Bangladesh is lower compared to that of many other wheat growing countries.

Recent efforts to improve the present yield level of wheat in Bangladesh could not bring any noticeable changes because of several production constraints. One of the major reasons for this failure in yield improvement is late planting of wheat (Islam *et al.*, 1993). In Bangladesh about 85% of the total wheat area follows previous rice crop (Saunders, 1991) and over 60% of the total wheat crop is cultivated at late sowing conditions (Badruddin *et al.,* 1994). Wheat plants suffer from high temperature stress from anthesis to maturity period due to short winter season and late sowing. This high temperature stress results in faster senescence of foliage, poor assimilate synthesis, reduced translocation of photosynthates to the developing grain and greater respiratory losses (Al-Khatib and Paulsen, 1984). The net effect of heat stress at this stage lowers the kernel weight due to reduced grain filling period, grain filling rate or the combined effect of both (Tashiro and Wardlaw, 1989). Chowdhury and Wardlaw (1978) reported that the optimum temperature for grain development of wheat lies within a range of

15/10°C to 18/15°C. Grain weight was reduced at higher temperature above a mean of about 16°C and with the increase in temperature from 21/16°C to 30/25°C, the duration of grain growth was reduced by 38%. Therefore, heat stress is a major factor limiting the productivity and as such time of sowing has a major bearing on the yield of wheat. So, identification of suitable wheat varieties for late seeded warmer conditions would be an important step for achieving high yield potential of wheat. Relatively heat tolerant variety can serve this purpose. In Bangladesh although some varieties were identified for late sowing conditions (Islam *et al.,* 1993 and Ahmed *et al.,* 1975), but the heat tolerance of these varieties is still obscured under Bangladesh conditions. However, the heat tolerance of wheat genotypes can be determined through imperical (yield performance) and/or analytical (morpho-physiological yield related traits) method. Among the methods membrane thermostability (MT) test is a widely accepted laboratory procedure for determining post-anthesis heat tolerance of wheat. Therefore, considering the above importance the present investigation was carried out with the following objectives -

(i) to determine the relative heat tolerance in ten recommended wheat varieties through membrane thermostability test, and

(ii) to evaluate the performance in grain development, stem reserve translocation and relative yield and yield components of heat tolerant and heat sensitive varieties under late seeded warmer conditions.

CHAPTER II

REVIEW OF LITERATURE

A very little work has been done on heat tolerance in wheat under high temperature or late seeded warmer conditions in Bangladesh. But numerous work has been done in this area in different wheat growing countries. Most of them were conducted in controlled conditions. However, information available in respect of heat tolerance in wheat pertinent to present study are presented in this section.

2.1 Membrane thermostability and heat tolerance

Metabolic activities such as photosynthetic activities and respiration and more sensitive to heat stress in cool season than warm season species (Bjorkman *et al.*, 1980). A cell membrane system that remains functional during heat stress finally contributes to adaptation of plants to high temperature (Raison *et al.*, 1980). This is especially important during the grain filling period, since grain growth is greatly reduced by environmental conditions which adversely affect assimilate supply (Evans *et al.*, 1975) or utilization (Bhullar and Jenner, 1985, 1986).

Sullivan and Ross (1979) measured the amount of electrolyte leakage from leaf discs bathed in deionized water after exposure to a heat shock treatment. They interpreted the measurement as an indicator of membrane thermostability (MT) in response to heat stress. They used this MT procedure to identify genetic variation in heat tolerance in grain Sorghum, *Sorghum bicolor* (L) Moench. Genetic variation determined by this procedure was related to differences in whole plant photosynthesis under high temperatures, as well as field performance of several cultivars grown under high temperature stress.

The electrolyte leakage or membrane thermostability (MT) test was conducted by Shanahan *et al.* (1990) at anthesis on flag leaves of eight field grown genotype of spring wheat (*Triticum aestivum* L.). Based on MT values, genotypes were grouped as heat tolerant (HT, n = 4) Vs. heat sensitive (HS, n= 4). The HT and HS genotypes produced similar grain yields at the northern and central locations. However, the heat tolerant group of genotypes produced 21% more grain yield than the HS group at southern site, which was considerably warmer during the grain filling period than the other two locations. Average temperature during July were 19.5, 21.7 and 23.4ºC at the northern central and southern locations respectively. These results suggest that the greater MT of HT genotypes was associated with productivity only under more extreme temperature. Based on results of this study it seems that MT test is a useful screening procedure for selecting HT genotypes of spring wheat.

Saadalla *et al.* (1990) determine the relationship between membrane thermostability (MT) and other agronomic traits of winter wheat (*Triticum aestivum* L.). A trial of 144 genotypes were evaluated for MT and the results were expressed as relative injury (RI). Among the genotypes the relative injury varied significantly with a range of 31 to 78%. Based on RI values, the genotypes were separated into three groups : heat tolerant (HT), intermediate (I) and heat sensitive (HS). Accordingly, 27 genotypes were classified as HT, 71 as I and 46 as HS. Yield, grain volume weight, and kernel weight were greater for HT VS I or HS. Thus heat tolerance as evaluated by the MT test, was associated with grain yield and quality. These results suggest that the MT test would be a suitable procedure for selecting heat tolerant winter wheat genotype in a breeding program.

Hossain *et al.* (1995) developed an improve method of determination of membrane thermostability (MT) for screening heat tolerance and sensitive varieties in *Brassica*. Among four varieties of cabbage (*Brassica oleracea* var. *Capitata* L.) studied, the varieties 'Yoshin' and 'YR kinshun' were the most tolerant followed by 'Sousyu', while the variety 'kinkei no. 201' was heat sensitive. The heat killing time of heat tolerant and sensitive varieties was 150 and 120 min at the elevated temperature of 55°C respectively. In Chinese cabbage (*B. campestris* var. *Pekinesis* L.) the varieties 'Kenshin' and 'No. 11' were heat tolerant, whereas the variety 'Chihiri 70' was heat sensitive. In Chinese kale (*B. oleracea* var. *alboglabra* Bailey), the variety 'Full white' and 'Sen-yo shirobana' were heat tolerant while the variety 'large leaf' was heat sensitive. In general heat tolerance ability was higher in Chinese kale compared to cabbage and Chinese cabbage. The heat tolerance trait in the interspecific somatic and sexual hybrids between cabbage X chinese cabbage and between Chinese kale X Chinese cabbage was intermediate between that of the parents. So, for screening and analysing the genetic variability of heat tolerant variety the MT test is efficient and used.

Chen *et al.* (1982) reported that heat tolerant and susceptible genotypes did not differ in heat killing time when the plants were grown at 20/15°C day/night temperature; however, the differences became dramatic after the plants were acclimated at temperature above 30°C for 24 hours. Heat killing time was a function of the acclimating temperature with the optimum acclimating temperature found to be 35 to 37°C. Rate of heat acclimating was very fast, and a continuous high temperature treatment appeared to be necessary to retian the level of heat tolerance. They also suggested that the heat hardiness of crop plants can be detected by measuring the iron leakage immediately after a stress of high temperature, i.e. 50°C. Leaves could serve as the testing tissue for screening heat tolerant genotypes with plants as young as 1-month old.

Saadalla *et al.* (1990) reported that identification of heat-tolerant winter wheat (*Triticum aestivum* L.) genotypes for the central and Southern Great Plains of the USA as well as other areas of the world is desirable. They also suggested that suitability of using the membrane thermostability (MT) test for ascertaining heat tolerance of winter wheat was determined and genetic differences in MT highly dependent on the type of hardening treatment or temperature to which plants are exposed prior to sampling. Additionally they observed genetic differences in MT with soybean (*Glycine max.* (L) Merr.) and noted genotypic variation in MT with various turfgrass species using this procedure. Their treatment protocol (for MT test at 49°C) that produced an average RI (Relative injury) value of 57% would be the most appropriate for assaying seedling of winter wheat, since this level of RI provides the greatest sensitivity in detecting genetic differences.

2.2 Grain development, yield and yield component influenced by temperature

Hexaploid wheats are of temperate origin (Harlan and Zohary, 1966). The optimum temperature for wheat crop is about 20°C (Al-Khalib & Paulsen, 1984). Like most species of temperate origin, wheat does not tolerate prolonged exposures to temperatures exceeding 35°C (Gusta and Chen, 1987). Heat stress adversely affects the plant growth and thus limits wheat productivity in many region of the world, particularly countries in the tropical belt between 23°N and 23°S latitude (Fischer & Byerlee, 1991).

Crop growth resource components like leaf area development (LAD) and tillering are determined during GS_1 phase (emergence to double ridge). Sensitivity to heat stress during this phase is expressed as decreased duration of GS_1, reduced LAD, number of leaves and spike bearing tillers (Shpiler and Blum, 1986). Mean temperature of 16 to 20°C is favourable for tillering. Duration of GS_1 was reduced by about 34d with concomitant loss (82%) of leaf area index and total spike m^{-2} when mean seasonal temperature changed from 12.2 to 27.5°C (Acevedo *et al.*, 1991).

Number of grains per spike is determined during GS_2 phase (double ridge to anthesis). Shpiler and Blum (1986) observed that the cultivars which sustained the highest yield in hot environments were able to maintain the longest duration of GS_2 and had the highest number of grain per spike. This is the most sensitive stage and its duration is drastically reduced due to heat stress. There is a corresponding decrease in spikelet/floret number per spike and grain number per unit area. Assuming that grain number is solely controlled by prevailing temperature, Abrol *et al.* (1991) observed a linear regression of grain number on the mean temperature from sowing to anthesis. The regression shows a reduction of 5.5% in grain number for every 1°C increase in temperature. Acevedo *et al.* (1991) observed detrimental effects of high temperature on grain number and the duration of spike development during GS_2 stage.

Grain filling duration generally has inverse relationship with the prevailing temperature. Heat stress during GS_3 phase (anthesis to maturity) results in faster senescence of foliage, poor assimilate availability, reduced translocation of photosynthates to the developing grain and grater respiratory losses (Al-Khalib & Paulsen, 1984). Consequently, the net effect of heat stress at this stage (GS_3) is lower kernel weight due to reduction in the grain-filling period, grain filling rate or the combined effect of both (Tashiro & Wardlaw, 1989). Based on several studies, Acevedo *et al.* (1991) concluded that grain weight was reduced from 4 to 8% for each 1°C rise in daily mean temperature.

Photosynthesis is one of the most sensitive process to heat stress (Blum, 1988). Photosynthetic rates decline due to acceleration of senescence during vegetative and reproductive phase (Al-Khalib & Paulsen, 1984). High temperature stress mainly affects thylakoid membrane activities and damage the thermolabile photosystem II reaction centre. Al-Khatib and Paulsen (1990) measured net photosynthesis, thylakoid membrane stability, chlorophyll variable fluorescence and productivity in 10 genotypes from major world wheat producing regions under moderate (22/17°C, day/night) and high (32/27°C day/night) temperature for 2 wk. at seedlings or from anthesis to maturity. They found that heat stress decreased mean photosynthesis rates by 32 and 11%, chlorophyll variable fluorescence by 42 and 11% and mean total biomass by 32 and 15% in seedling and maturing plants respectively. Also heat stress reduced mean grain weight by 20% and mean grain yield by 23% relative to moderate temperature. Thylakoid stability varied similarly to high temperature. Decreased photosynthetic rates and diminished productivity were significantly correlated at both growth stage. Relative grain yields were strongly influenced by decreased duration photosynthetic actively, which ranged widely in the 10 genotypes. Genotypes those were most tolerant of high temperature had stable rates and/or long durations of photosynthetic activity, high grain weights and high harvest indices, which are potential selection criteria.

Thermotolerant mutant WH 147M showed a considerably lower decrease in the rate of photosynthesis as compared to sensitive cv. WH 147 leaves. Stress of 45°C for 1h resulted in 82 and 33% reduction in photosynthetic activity in WH147 and WH147M, respectively at a 50°C treatment for 1h, the leaves of WH147 completely lost photosynthetic activity, whereas the loss was only 30% in WH147M (Kaur *et al.*, 1988).

Under high temperatures, the wheat crop completes its cycle much faster than under normal temperature conditions (Fischer 1985). All crop stages have a short duration. Consequently, there are fewer days to accumulate assimilates during the life cycle and production of biomass is reduced (Fischer and Maurer 1976). High temperatures accelerate organ production without any increase in net photosynthesis (Begga and Rawson 1977) resulting in smaller organs.

High temperature in the post anthesis period shortens the duration of grain-filling (Wiegand and Cuellar 1981) such that each degree increase during grain filling results in about three days decrease in the duration of filling regardless of cultivar (Asana and

Williams 1965, Begga and Rawson 1977). Evans and Wardlaw (1976) and Sofield *et al.* (1977) concluded that neither illumination conditions nor grain-filling rates affects the duration of grain filling.

Bhatta *et al.* (1994) evaluated the variation of twelve spring wheat genotypes of similar maturity in grain yield, morphophysiological characters, and the relationship between grain yield and plant traits over two planting periods. Most characters were altered when planting was delayed by one month from the normal seedling date. Declines in grain yield, kernels per spikelet and 100 grain weight were relatively of small magnitude. Average grain filling duration was shortened by four and maturity by six days in the later planted warmer conditions. Despite these reductions, some genotypes showed stability of grain yield between the two planting periods indicating possible genetic variability in grain filling rate. Correlation studies indicates that flag leaf sheath length, extrusion length, plant height, spike length, kernel per spike and biological yield are important determinants of grain yield in wheat under Los Banos conditions.

Accelerated development, enhanced respiration and numerous indirect effects complicated interpretation of high temperature injury to plants (Chowdhury and Wardlaw, 1978; Fischer, 1985; Rawson, 1988; Sofield *et al.*, 1977; Spiertz, 1977; Wardlaw *et al.*, 1980; Welbank *et al.,* 1968).

High temperature (up to 30/25°C day/night) after anthesis reduced grain yield of wheat by reducing weight per grain, rather than grain number (Wardlaw *et al.*, 1989). Final kernel weight is determined by rate and duration of dry matter accumulation. Generally reduced kernel weight in heat stressed wheat results from shorter duration rather than reduced rate of grain growth (Sofield *et al.*, 1977; Warringhton *et al.* 1977; Wiegand and Cuellar, 1981). Thus, heat stress during grain-fill hastens maturation of the grain, resulting in smaller, often shrivelled grains.

Productivity of wheat and other temperate species falls markedly at high temperatures (Bhullar and Jenner, 1983; Rawson, 1986; Shpiler and Blum, 1986; Wardlaw *et al.,* 1980). Genotypes within species differ in response to high temperatures, however, indicating substantial genetic variability for the trait. Wheat genotypes for instance, incur differential injury from high temperatures during vegetative growth (Shpiler and Blum, 1986), reproductive growth (Bhullar and Jenner, 1983; Wardlaw *et al.*, 1980), or both periods (Rawson, 1986; Todd, 1982). Many wheat genotypes can be considered high temperature tolerant (Rawson, 1986).

Al-khatib and Paulsen (1990) evaluated the yield performance of 10 wheat genotypes grown under moderate (22/17°C, day/night) and high (32/27°C, day/night) temperature. Yield component of 10 genotypes at maturity reacted differently to high temperature. Spike per plant significantly decreased in 3 genotypes and increased in one genotype as the temperature increased where as kernel per spike decreased in four genotypes. Kernel weight decrease significantly in all genotypes by a mean of 20% whereas the reduction range was about 10% to 30%. Grain yield means declined from 0.75 to 0.58 g tiller^{-1} or 23% from 22/17 to 32/27°C, temperature. Yields were constant for 3 genotypes and decreased >40% for three genotypes. Harvest index of all 10 genotypes was affected little by temperature, but individual genotypes responded very differently.

Chinoy (1947) compared grain weight per plant and 1000 grain weight of wheat varieties group into eight classes according to flowering time, which ranged from 90-100 to 160-170 days. With delay in flowering, grain developed at increasingly higher temperatures and lower humidity, with the consequence that both 1000 grain weight and grain yield per plant diminished progressively. Pal and Butany (1947) also concluded that 1000 grain wt. was reduced for late sowing because of the high temperatures prevalent at the time of grain ripening. Chinoy and Sharma (1957, 1958) found that external conditions such as temperature were mainly responsible for under developed or empty grain, and not genetic factor as previously held.

In a series of experiments in which wheat was grown in pots in the open, Asana and Saini (1962) compared the 1000 grain weights for two varieties Pb.C. 281 and N.P. 720. They observed that 13.9 and 17.8% losses in grain weight for Pb. C. 281 and N.P. 720 respectively for a 5°C rise in the mean temperature and assuming that yield attribute in determined solely by temperature.

Asana and Williams (1965) carried out an experiment to determine the effects of high temperature on grain development and yield in wheat. Two Australian and three Indian cultivars to wheat were exposed from a week after anthesis until maturity, to day temperatures of 25, 28 and 31°C and night temperature of 9 and 12°C. There was a mean reduction in yield of 16% for 6° rise in day temperature but the cultivar did not differ significantly in their response to these temperatures. There were no significant effects of night temperature on grain weight but stem weight was less at 12°C. Mean weight per grain provided the best index of treatment effect and there were considerable differences between cultivars for this attributes. Relative effects of treatment were specially meaningful and grain weights per main-shoot ear were affected to the same relative extent by treatment, but were inherently more variable. Senescence was hastened only slightly by high day temperature, and there were no differential effects between cultivars in this respect. From growth analysis for the Australian cultivars Ridley and Diadem indicated the developing grain of Ridley had a greater capacity for growth than that of Diadem from the earliest stage. This together with the confirmation of grain size as a very stable character for all varieties to the developmental and synthetic activity of the grain as an important determinant of grain yield.

High temperature (41°C) causes a decrease in the potential photosynthetic rate in both heat resistance and susceptible varieties although the decrease was smaller are recovery ability higher in the resistance variety (Volkova and Koshkin 1984).

Zeng *et al.* (1985) observed high temperature (27°C average) for 7 days around pollen meiosis also reduced grain set, and in some cultivars floret were lost.

Day/night temperature 28/20°C accelerated grain development compared with that at 23/15°C, while DM accumulation and cell division occurred at a higher rate but had a shorter duration (Nicolas *et al.,* 1984).

High temperature (35° day/25°C night) adversely affected the source and sink process. Heat stress accelerated the normal decline in viable leaf blade area and photosynthetic activity per unit leaf area. Grain filling rate decreased from the lowest (25° day/15°C night) to the highest temperature (35°/25°C), but the change was smaller than the decrease in grain filling duration at same temperature. A major effect of high temperature appeared to be acceleration of senescence, including cessation vegetative and reproductive growth, deterioration of photosynthetic activities (Al-Khalib and Paulsen, 1984).

Kanani and Jadon (1985) assessed 110 wheat genotypes for ability to with stand high temperatures when sown early to fit into a rotation with groundnut 18, including Hindi 62, C306, K65, NP846, HJ72-6, HJ72-50, HJ 72-65, HI 617, and W6357, were superior. These genotypes had higher values for yield and 5 yield-related traits when sown early than when sown late, for example, Hindi 62 yielded twice as much with early as with late sowing.

Amores-Vergara and Cartwrite (1984) observed that wheat cv. Sonora 64 was transferred to 27°C during 6 development stages and compared with control plants grown continuously at 17 or 27°C. The time from sowing to maturity was reduced more by later exposures (after anthesis to maturity) to high temperature. High temperature during the vegetative phase (sowing to flag leaf primordia) the transition phase (flag leaf primordia to double ridge) and spikelet initiation resulted in greater setting of fertile florets but a decreased in the number of fertile florets/ear and individual grain wt.

Poorten (1983) reported that in field and growth cabinet studies with wheat, the time interval between anthesis and the commencement of linear grain DM accumulation varied little among cv. for both spring and winter wheat but it was inversely related to temperature. The response of filling duration to temperature differed among cv. changes in assimilate supply to the grains had little or no effect on filling duration. Both the final grain wt. and maximum number of endosperm cells established were positively correlated with ovary wt. at anthesis.

High temperature accelerates heading date causes shorter vegetative period (Balla, 1983). Tashiro and Wardlaw (1984) observed that when wheat cv. Banks was subjected to a range of temperature from 17.7 to 32.7°C starting 7d after the 1st anthers appeared, grain wt. at maturity was reduced by about 5% for each 1°C rise in temperature within this range and there was a reduction in the duration of grain growth with increasing temperature.

Jhala and Jadon (1989) studied that grain growth rate (mg/spike per day) from the 1st to the 8th week after anthesis (WAA) in 15 wheat cultivars sown on 15 November (optimum date) or 30 November. There were significant differences between cultivars for grain growth rate especially during 1st 4 WAA. Grain growth rate was the highest in the 3rd and 2nd WAA for crops sown on 15 November and 30 November respectively. Grain growth rate was higher in crops sown on 15 November than in those sown on 30 November. Cv. Lok 1, WH 147, HI784, Kalyansana and HJ 74-27 had initial high grain growth rate and could be used for breeding cultivars suitable for late-sown conditions.

High temperature restricted grain growth by limiting sucrose conversion to starch (Maness, 1988).

Rawson (1988) examined the hypothesis that rapid phenological development, poor biomass production and sterility are major factors leading to the poor yields in wheat grown from sowing to maturity at high temperatures. 24 wheat genotypes at moderate temperatures were compared in a glasshouse study of 'minicanopies' of plants grown at 30/25°C. Absolute differences among genotypes in growth and floral development became small at these high temperature. However, a short vegetative period did not prevent rapid rates of biomass production and the emergence of at least 6 ears/plant. There was little evidence that high temperature resulted in floret sterility except 2 genotypes and consequently harvest index was generally very high. The range in grain yields among genotypes was 0-10 g/pant; >70% of genotypes gave >7 g/plant. It is suggested that high temperature tolerance already exists in many common wheats.

From 2 trials each containing 16 bread wheat genotypes, planted for 2 years under late sowing conditions of high temperature (above 30ºC) and one year at the normal sowing time, He and Rajaram (1993) observed that yield, grains per spike, biomass and plant height are more thermo-sensitive than spike number per square meter, 1000 grain weight and test weight. The grain filling rate was more temperature-sensitive than days to anthesis and duration grain filling. Simple phenotypic correlation analysis indicated that yield was highly and positively correlated with grains/spike, biomass and harvest index (HI) independent of seasons and genotypes under high temperatures. Grain per spike accounted for variation in yield ranging from 35.2 to 78.1%. Effect of earliness on the yield under high temperature was highly dependent on the temperature regime during the heading stage. Grains per spike, biomass, HI and test weight could be considered potential selection criteria for yield under high temperature. Analysis of yields under normal and late sowing conditions failed to reveal any association between the yield potential in normal sowing date and the performance of varieties under high temperature.

Wheat variety HD 2428 and kalyansona were compared by Shukla *et al.* (1992) for adaptability under pot culture by exposure to high temperature treatments (8ºC above ambient) in weeks 1 through 4 after anthesis. Dry matter accumulation of grain in the top, middle and bottom spikelets of the spike, at 7 grain locations was recorded in weeks 2 and 3. The treatments adversely affected grain weight for HD2428 at all 3 spikelet positions, with up to 35% reduction in the first 5 grain location. Kalyansona was only marginally affected. This indicates that the characteristic adaptability of kalyansona to different agroclimatic regions is associated with the tolerance of physiologically old grains to higher temperature.

Ahmad *et al.* (1989) reported that in pot trial the effects of temperature stress (30-39ºC max. and 13-16ºC min. temperature) for 7, 14, 21 and 28d starting at anthesis on wheat cv. Punjab 85 and Faisalabad 85 were compared with control temperature (23-30ºC max. and 10-13ºC min.). Grain yields of each cultivar decreased with increasing temperature stress duration. Faisalabad 85 was less sensitive to heat sensitive to heat stress than Punjab 85. Under heat stress a higher grain wt. was found in the middle portion of spikes compared with the ends.

Islam *et al.* (1993) evaluate the performance of the existing (Sonalika) and released wheat varieties (Ananda, Kanchan, Barkat, Akbar, Aghrani) seeded from 1 November to 15 January at 15 days interval. Grain yield, spike/m^2, grain/spike and 1000-grain weight were significantly affected by sowing date and variety. Maximum grain yield was obtained with variety Kanchan when sown on 15 November which was identical to Akbar and Barkat. Aghrani variety performed better than all other varieties when sown December and January. Sonalika variety also showed lower yield than the other varieties when seeding was done in December and January. Different yield component of these 6 variety at maturity reacted differently to late seeded conditions. Delay sowing caused significant reduction in grain weight due to higher temperature at grain filling stage. Evans *et al.* (1975) and Mudholkar (1981) reported that higher temperature at grain filling stage was one of the important reasons for lower grain yield in wheat crop.

2.3 Stem reserves translocation

The final grain weight is the function of pre-anthesis and post-anthesis translocation of stem reserves and assimilation of carbondioxide. In barley and other cereals the number of ears/plant and number of grain/ear are determined by the time of anthesis and thereafter yield depends entirely upon the weight per grain achieved at harvest (Gallagher and Biscoe, 1978). Various estimations have so far been made regarding the contribution of stem reserves by carbondioxide, gas exchange and by shading different plant parts (Austin *et al.*, 1977 and Rawson and Evans, 1971). Most of the above works emphasized that maximum possible contribution to grain weight by material assimilated before anthesis was less tan 20%, although under adverse environmental conditions it many increase upto 74% of the final grain weight (Gallagher *et al.* 1975).

Pre-anthesis stem contribution towards the final grain weight is determined by net loss in weight of the above ground vegetative organs between anthesis and maturity with the differences between yield and net assimilation (Gallagher *et al.*, 1975). Sadeque (1990) reported that the pre-anthesis stem contribution varied from 10-18% of the final grain weight in Barley and Austin *et al.* (1980) measured 11-12% of the final grain wt. in barley translocated from pre-anthesis assimilation under normal environmental conditions.

CHAPTER III

MATERIALS AND METHODS

3.1 Location

The experiment was conducted at the research farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Salna, Gazipur during November, 1997 to April 1998. It is located at the Centre of Madhupur Tract ($24^{0}05^{1}$N latitude and $90^{0}16^{1}$E longitude) at an elevation of 8.4 m above the sea level.

3.2 Soil and climate

The farm soil of BSMRAU belongs to Salna series of Shallow Red-Brown Terrace soil type (Brammer, 1971; Shaheed, 1984). Under USDA soil taxonomy the experimental soil falls under Ochrept sub-order under the order inceptisol. The texture of soil is silty clay in surface layer and silty clay loam in sub-surface region. Information of basic physico-chemical properties of the soil are presented in Appendix 2.

The experimental site is situated in the sub-tropical climate zone characterized by heavy rainfall during the months from May to September and scantly rainfall in rest of the year. Meteorological data on rainfall, temperature, relative humidity from November, 1997 to April 1998 were obtained from the department of Plant Physiology of Bangladesh Rice Research Institute, Joydebpur, Gazipur 1701 (Appendix 3).

3.3 Experimental design and treatment

The experiment was laidout in a split plot design with four replications. The size of unit plot was 3 m X 2m having a plot to plot and block to block distance of 0.75 m and 1.0 m, respectively.

Main plot treatment : Two sowing time

Optimum sowing	(November 30)
Late sowing	(December 30)

Sub-plot treatment : Ten variety

Wheat varieties- Aghrani, Akbar, Ananda, Balaka, Barkat, Kanchan, Pavon, Protiva, Sawgat and Sonora.

3.4 Land preparation

The land was prepared very well by deep and cross ploughing with a tractor followed by harrowing and laddering. The weeds and stables were removed and the main plots and sub-plots were prepared.

3.5 Fertilizer application and irrigation

A fertilizer dose of 100-60-40-20 kg/ha N, P_2O_5, K_2O and S was applied in the form of Urea, Triple Super Phosphate (TSP), muriate of potash, and gypsum, respectively. Half of N and full dose of P_2O_5, K_2O and S were applied as basal dose and the remaining amount of N was applied 20 days after seeding followed by an irrigation. Three irrigation were given at crown root initiation, maximum tillering and grain filling stages.

3.6 Sowing and intercultural operations

Ten wheat varieties, Aghrani, Akbar, Ananda, Balaka, Barkat, Kanchan, Pavon, Protiva, Sawgat and Sonora were used as experimental materials. The seeds were collected from Wheat Research Centre, Nashipur, Dinajpur. Seeds were sown on November 30, 1997 and December 30, 1997 in rows 20 cm apart. November 30 as regarded as optimum sowing time whereas the December 30 was late sowing. Thinning was done at 15 days after sowing to maintain desired plant population. The crop was kept weed free, and pest and diseases were controlled regularly.

3.7 Membrane thermostability (MT)

Procedures used for measuring MT were the same as those described by Hossain *et al.* (1995). Leaf sample were collected at anthesis from flag leaves of five randomly selected plants of each variety.

From a flag leaf two leaf discs were collected using a leaf puncher 10.0 mm in diameter (CAT 162 MODEL ROUND OPEN INDUSTRY CO. LTD., JAPAN) and washed three times with deionized water to remove electrolytes adhering to leaf tissue, as well as electrolytes released from cut cells on the periphery of leaf discs. The test tubes were drained with deionized water also. The leaf samples were then placed in 25 mm X 150 mm test tubes and a piece of cotton was put on the leaf-disc inside the test tube to prevent any injury of the discs by the electrode bar during the conductance measurement. Thereafter 20 ml of deionized water was added. Then the initial conductivity reading (I) was taken with an Electric Conductivity (EC) meter (WINTEK CONDUCTIVITY METER, MODEL 2001, JAPAN). The test tubes were covered by aluminium foil and placed in a thermostatically controlled water bath (MODEL SM-05, TAITEC, JAPAN) maintaining a constant temperature of 55°C. Electric conductivity reading (E) was taken every 30 minutes upto 4 hours at the elevated temperature of 55°C. Subsequently the samples were autoclaved at 121°C for 15 minutes to completely kill the leaf tissues. After autoclaving the samples were again placed in a water bath at 55°C to adjust the elevated temperature and after 30 minutes of incubation, final conductance (F) was measured. The percentage of injury induced by the elevated temperature during the time course (30 minutes) was calculated as follows :

$$\text{Injury (\%)} = \frac{E - I}{F} \times 100$$

where, I is the initial conductance
E is the elevated temperature conductance
F is the final conductance after autoclaving

The time required to cause 50% injury at 55% was defined as the heat killing time. Longer heat killing time in MT test indicates heat tolerance and shorter heat killing indicates heat sensitivity of wheat varieties.

3.8 Grain growth

At anthesis 55 ears were tagged from each plot. Five tagged ears were harvested to quantify grain growth at every 4th day beginning from four days after anthesis. The harvesting of ears of all varieties was continued upto 44 days after anthesis (DAA) for

November 30 sowing and 36 days after sowing for late sowing (30 December). The harvested ears were kept at 70ºC for 72 hours for drying. The dried samples were placed in a desiccator to avoid moisture absorption. The grains were separated from husk and 100 grains of each variety was weighed with an analytical balance (AND Electronic Balance model ER 180 A, A & D Company Limited, Tokyo, Japan).

The absolute grain growth rate (AGR) was calculated using the formula -

$$\text{AGR} = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

W_1 = Grain dry weight at initial time
W_2 = Grain dry weight at final time
t_1 = Initial time
t_2 = Final time.

3.9 Contribution of pre-anthesis stem reserves towards the final grain weight

For determining the pre-anthesis stem contribution towards the final grain weight, the method of Gallagher *et al.* (1975) has been used. This is based on the net loss in weight of above ground vegetative organs between anthesis and maturity with the differences between yield and net assimilation. It was calculated as -

Pre-anthesis stem contribution (%)

$$= \frac{\text{Change of stem dry weight (g) from anthesis to maturity}}{\text{Change of grain dry weight (g) from anthesis to maturity}} \times 100$$

$$= \frac{S_2 - S_1}{G_2 - G_1} \times 100$$

Where,

S_1 = Stem dry weight (g) at anthesis
S_2 = Stem dry weight (g) at maturity
G_1 = Grain dry weight (g) at anthesis
G_2 = Grain dry weight (g) at maturity

After two weeks of sowing, the main stems were marked by colour thread for easy identification during subsequent sampling.

Five main stems were taken from each plot as sample at anthesis as well as at final harvest for measuring ear and stem weight. After collection, both ear and stem were dried at 85°C for 48 hours and weighed. After drying grains were separated from husk and weighed.

3.10 Yield and yield components

Number of ear per plant

Number of ear per plant was counted from 10 randomly selected plants in each plot. It was recorded at harvest.

Grain number/ear

The number of grain/ear was obtained by counting from 10 randomly selected ear per plot.

Thousand grain weight

From each plot, thousand grain were taken randomly and the total weight was recorded. The grain weight was adjusted to 12% moisture content.

Grain weight per main shoot ear

Grain weight per main shoot ear was determined from 10 randomly selected main shoot ear which were identified before appearance of tiller (2 weeks after sowing).

Grain yield

Grain yield was recorded from a $4m^2$ (2m X 2m) central area and converted to ton per hectare and adjusted to 12% moisture content.

3.11 Relative performance

Ratio of late sowing (30 December) performance to optimum sowing (30 November) performance was expressed in percentage and was calculated as Asana and Williams (1965).

$$\text{Relative performance } (\%) = \frac{\text{Late sowing (30 Dec.) performance}}{\text{Optimum sowing (30 Nov.) performance}} \times 100$$

3.12 Analysis of data

Recorded data on yield and yield components were analyzed through partitioning the total variance with the help of computer by using MSTAT Program. The treatment means were compared by using Duncan's Multiple Range Test (DMRT).

In membrane thermostability test, stem reserves translocation and grain growth only mean values were used.

CHAPTER IV

RESULTS AND DISCUSSION

4.1. Screening of relatively heat-tolerant and sensitive varieties in wheat by membrane thermostability

Heat-killing time (time to at least 50% injury) of wheat varieties was longer for Aghrani (210 min), Barkat (210 min) and Pavon (240 minutes) compared to the varieties Akbar (150 minutes), Kanchan (150 minutes), Protiva (120 minutes), Balaka (90 minutes), Sawgat (90 minutes) and Sonora (60 minutes) grown under natural climatic conditions (Table 1). The injury of Ananda was less than 50% during 240 minutes.

Among the ten wheat varieties, Aghrani and Barkat reached to the heat killing injury during 210 minutes whereas Pavon reached to the same during 240 minutes after exposed to 55°C temperature. But the variety Ananda showed only 43.39% injury during 240 minutes. So the heat killing time of Ananda was found to be the longest than all other varieties used in this experiment. Hence, the varieties- Ananda, Pavon, Aghrani and Barkat were considered as relatively heat tolerant.

The percentage of killing injury for Akbar and Kanchan was 50.46% and 51.61% respectively during 150 minutes at a temperature of 55°C while the variety Protiva required 120 minutes for reaching killing injury 50.93% under same conditions. The varieties- Akbar, Kanchan and Protiva were considered as moderately tolerant.

Table 1. Relative heat tolerance of ten wheat varieties as determined by percentage of membrane injury of flag leaf tissue and time to attain that injury

Exposure time (min) at 55°C	Injury (%)									
	Aghrani	Akbar	Ananda	Balaka	Barkat	Kanchan	Pavon	Protiva	Sawgat	Sonora
30	31.02	36.18	24.93	37.95	21.13	39.14	23.92	39.28	45.42	46.02
60	32.65	42.90	27.97	48.70	26.92	41.62	28.87	43.09	48.72	**59.85**
90	42.09	45.73	30.16	**54.52**	32.31	47.49	34.65	47.24	**51.41**	66.38
120	45.51	48.08	33.21	58.63	38.12	49.41	39.25	**50.93**	56.41	68.89
150	47.91	**50.46**	35.18	62.67	43.63	**51.61**	43.35	53.19	58.85	71.41
180	49.66	52.30	37.29	64.96	49.31	52.76	46.67	56.42	64.50	72.80
210	**51.58**	54.97	40.36	68.33	**53.61**	53.76	49.13	57.98	67.25	74.90
240	52.92	56.52	**43.39**	71.36	57.93	54.54	**51.69**	60.98	69.26	76.28

The varieties- Balaka, Sawgat and Sonora were heat-sensitive because they required shorter time for reaching killing injury (50%). Balaka and Sawgat showed injury of 54.52% and 51.41% respectively during 90 minutes at a temperature of 55°C while the variety Sonora required only 60 minutes for reaching 59.85% killing injury under same conditions. Thus Sonora was the most sensitive variety.

This results apparently suggest the possibility that acclimatization capacity of the heat-tolerant wheat varieties would be higher compared to heat-sensitive varieties. Also higher acclimatization capacity was reported in tolerant varieties of Cabbage compared to sensitive ones (Hossain *et al.*, 1995). Genotypic differences in membrane thermostability in wheat was reported by many authors (Shanahan *et al.* 1990; Saadalla *et al.*, 1990). These differences would be a suitable indicator for determination of heat-tolerant genotypes of wheat.

4.2. Grain growth

Among the relatively heat-tolerant varieties, Aghrani and most heat sensitive variety Sonora were selected to study their grain growth pattern. Aghrani was exposed to higher temperature during grain filling period as its anthesis occurred about five days later (Fig. 1) compared to the other heat tolerant varieties. Results indicate that generally the grain growth had an initial lag period (low growth) just after anthesis before the linear increase in dry weight (Fig. 2). The linear growth phase (rapid growth) was followed by a decreasing growth rate during maturity. At November 30 sowing (optimum sowing) both Aghrani and Sonora attained their physiological maturity at 40 days after anthesis (DAA). At this sowing both varieties maintained their initial lag period for about 12 DAA and linear growth phase for about 28 days. Incase of absolute growth rate, both of Aghrani and Sonora maintained a growth rate of more than 1 mg/day/grain upto 24 DAA at November 30 sowing (Fig. 3). But in general, Aghrani had higher growth rate than Sonora during this period. Finally Aghrani attained higher grain weight compared to Sonora due to its higher growth rate. Spiertz (1979) reported similar findings that the rate of grain growth in addition to duration of grain growth may cause variation in grain yield.

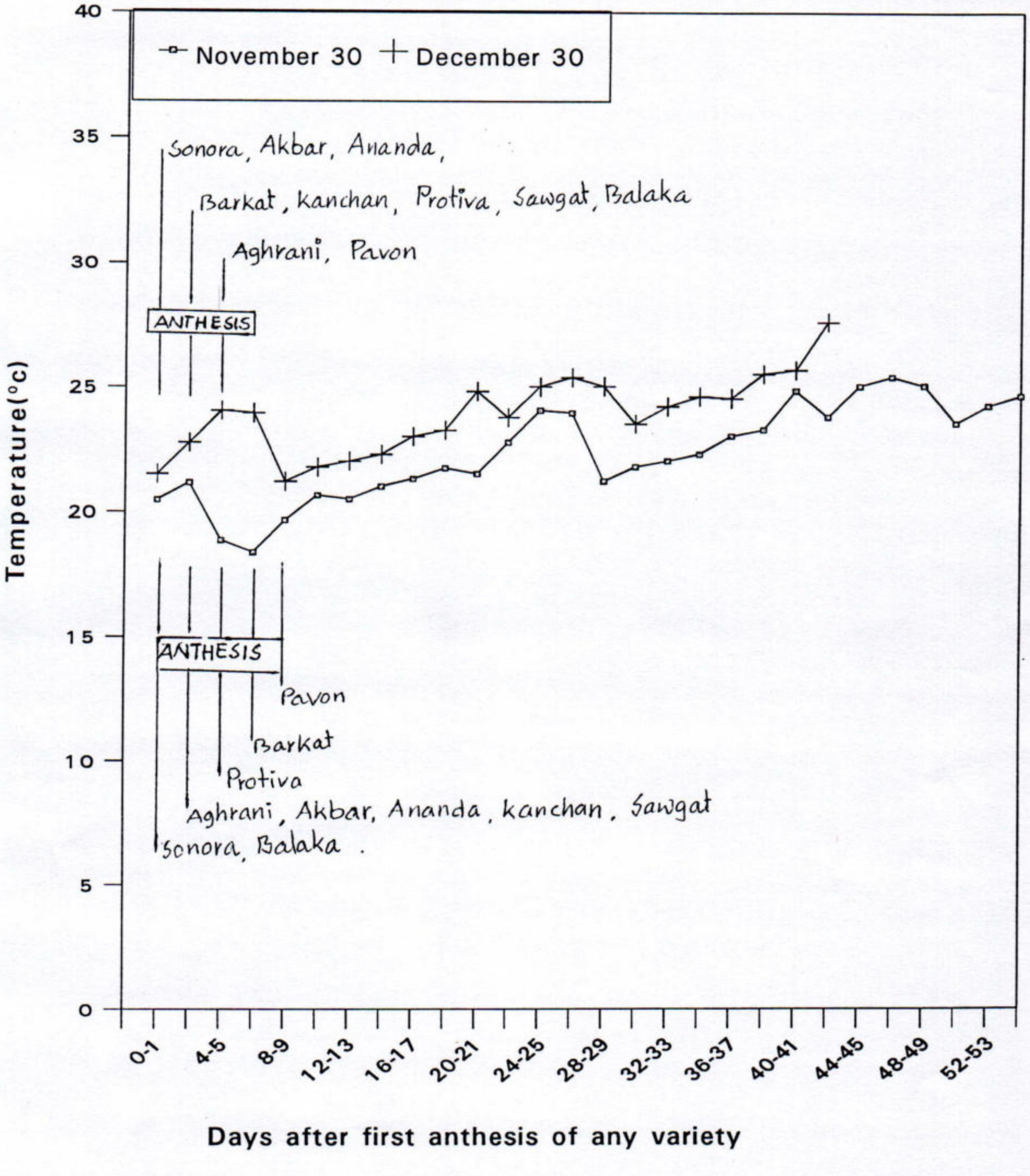

Fig.1 **Mean air temperature (°c) from anthesis to maturity period of wheat**

F

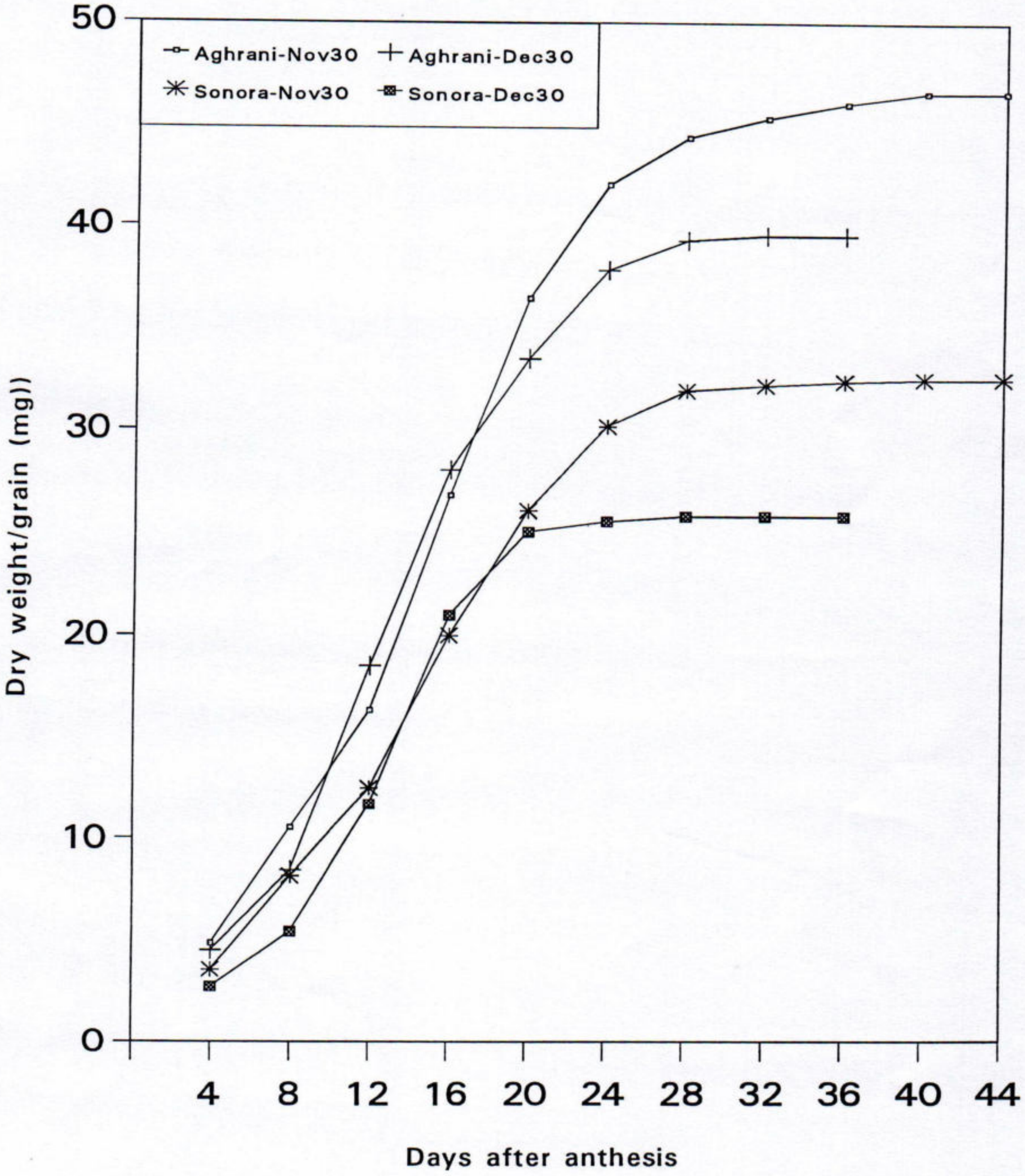

Fig.2 Effect of sowing date on dry weight of wheat grain.

For December 30 sowing (late sowing) the tolerant and the sensitive varieties had different grain growth duration and grain growth rate. Both Aghrani (tolerant) and Sonora (sensitive) reduced their grain filling period in late sowing compared to optimum sowing (Nov. 30). But the magnitude of this reduction were different for tolerant and sensitive varieties. The reduction of grain filling period for Aghrani (tolerant) was lower than Sonora (sensitive). The time took from anthesis to maturity was 32 and 28 DAA for Aghrani and Sonora respectively whereas at optimum sowing the both varieties had a common time (40 DAA) for physiological maturity. At late sowing (December, 30) conditions, the both varieties had an initial lag period about 8 days but in linear growth phase Aghrani and Sonora took 24 and 20 DAA respectively. In this sowing (Dec. 30), the tolerant variety (Aghrani) however, maintained a higher growth rate for longer duration (24 DAA) while the sensitive variety showed a rapidly declining growth rate after 20 DAA. This results agreed with those of Bhatta *et al.* (1994). Delay sowing caused a high temperature stress conditions at grain filling period resulting reduced grain filling period and rate but this reduction was lower in tolerant varieties than those of sensitive varieties. Similar statements were also made by Wiegand and Cuellar (1981), Asana and Williams (1965), Begga and Rowsan (1977) and Jhala and Jadon (1989).

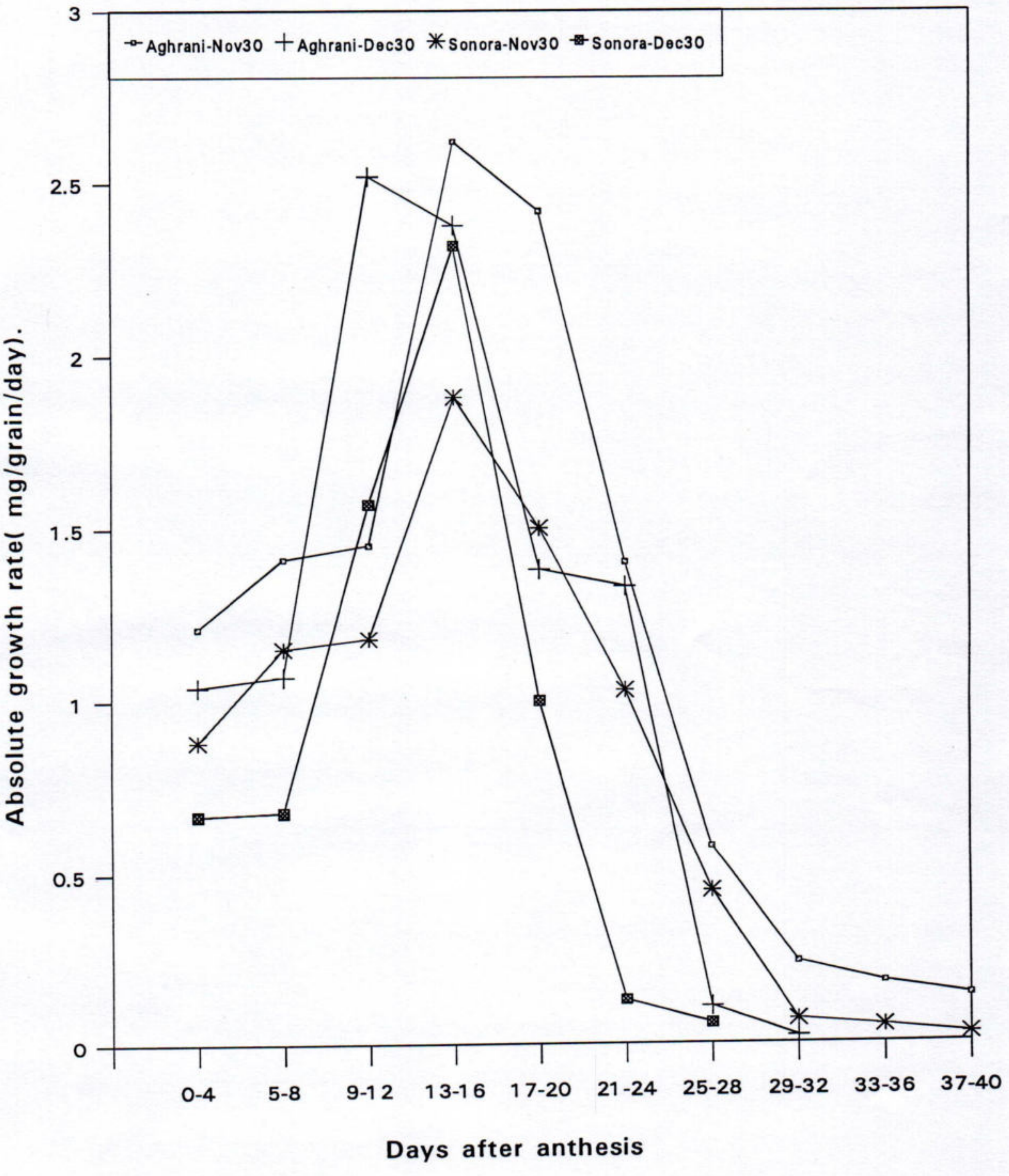

Fig.3 Effect of sowing date on absolute growth rate of wheat grain.

4.3. Contribution of pre-anthesis stem reserves towards the final grain weight

Estimation of pre-anthesis stem contribution was based on the method developed by Gallagher *et al.* (1975). The result showed that pre-anthesis contribution at November 30 sowing varied from 21.15 to 29.65% of the final grain weight but at December 30 (late sowing) conditions it was 13.08 to 32.95% (Table 2).

Table 2. Pre-anthesis stem contribution of wheat as affected by sowing time and variety

Treatments	Pre-anthesis stem contribution (%) of the final grain wt.	
	November 30	December 30
Aghrani	21.15	13.08
Akbar	25.50	20.05
Ananda	28.65	20.05
Balaka	27.85	32.95
Barkat	24.02	17.33
Kanchan	29.65	21.13
Pavon	27.70	22.80
Protiva	28.25	22.37
Sawgat	28.05	32.45
Sonora	24.70	30.65

At November 30 sowing, highest pre-anthesis contribution was found in Kanchan (29.65%) which is regarded as moderately heat tolerant variety in present study. Relatively tolerant variety Aghrani had the lowest stem contribution (21.15%) to its final grain weight. Heat sensitive Sawgat, Sonora and Balaka showed 28.05%, 24.70% and 27.85% pre-anthesis stem contribution respectively towards the final grain weight. Such results variation among the varieties in both sowing time in present experiment could be due to their varietal differences. This agree with the findings of Sadeque (1990) and Austin *et al.* (1980).

At late sowing (December 30) conditions relatively heat tolerant and moderately tolerant varieties (Aghrani, Ananda, Barkat, Pavon, Akbar and Kanchan, Protiva) gave lower pre-anthesis stem contribution (13.80% to 22.80%) compared to those of optimum sowing (21.15% to 29.65%). These results are in agreement with Al-khatib and Paulsen (1984) who showed that heat stress during anthesis to maturity resulted in reduced stem reserve translocation. Heat sensitive varieties Balaka, Sawgat and Sonora had higher stem contribution in late sowing heat stress conditions (30.65% to 32.95%) compared to optimum sowing conditions (24.70% to 28.05%).

Results from other studies with heat sensitive and tolerant varieties showed that at high temperature in post- anthesis period senescence was faster and potential photosynthetic rate was more reduced in heat sensitive varieties than heat tolerant varieties (Volkova and Koshkin, 1984). In other words, lower assimilation of post-anthesis CO_2 in sensitive varieties under heat stress conditions was evident compared to heat tolerant varieties. As a result of poor post-anthesis CO_2 assimilation more stem reserves could be used in grain development. This was supported by the findings of Gallagher *et al.* (1975) who observed an increase of pre-anthesis stem reserves contribution upto 74% under stressful environment.

In the present study therefore higher stem reserve translocation in final grain weight apparently indicated more heat sensitivity of Balaka, Sawgat and Sonora. However, further studies are required regarding the leaf senescence and photosynthesis for confirmation of the findings of this study.

4.4. Yield and Yield Components

a. Grain number per ear

Grain number per ear was significantly influenced by the interaction effects of sowing time and variety. At November 30 (optimum) sowing the variety Aghrani had the highest grain number (53.25) per ear which was at par with Pavon (51.63) and the variety Protiva produced the lowest grain number (39.30) per ear (Table 3). At December 30 (late sowing), the tolerant variety Aghrani attained the highest grain number (47.97) per ear whereas sensitive variety Balaka obtained the lowest grain number (30.73) per ear.

Table 3. Interaction effect of sowing time and variety on grain number per ear of wheat

Treatments	Grain number per ear	
	November 30	December 30
Aghrani	53.25 a	47.97 c-e
Akbar	48.85 cd	40.55 fg
Ananda	46.00 e	41.55 fg
Balaka	40.17 fg	30.73 i
Barkat	50.05 bc	40.20 fg
Kanchan	41.22 fg	34.20 h
Pavon	51.63 ab	41.28 fg
Protiva	39.30 g	31.77 i
Sawgat	42.13 f	31.31 i
Sonora	47.47 de	40.75 fg

Mean followed by the same letter(s) do not differ significantly at 1% level by DMRT.

At late sowing (December 30) conditions both tolerant and sensitive varieties significantly reduced their grain number per ear compared to optimum sowing (November 30). But the amount of reduction were different in tolerant and sensitive varieties. Heat tolerant varieties Aghrani and Ananda showed the lowest reduction in grain number and they maintained 90.08% and 90.32% relative grain number per ear respectively (Fig. 4). Other heat tolerant and moderately tolerant varieties viz. Barkat, Pavon, Kanchan, Akbar and Protiva maintained 80.31%, 80.00%, 82.97%, 83.00% and 80.84% relative grain number per ear respectively. However, the heat sensitive varieties Balaka and Sawgat attained 76.50% and 73.89% relative grain number respectively.

Unlike other heat sensitive varieties, Sonora being a heat sensitive variety maintained a higher (85.84%) relative grain number at late sowing compared to other sensitive varieties. Sonora showed relatively lower reduction of grain number among the sensitive varieties (Fig. 4). One of the reasons of such minimum reduction in grain number could be due to earlier anthesis of Sonora relative to other sensitive varieties when the mean temperature was not high enough (21°C) at late sowing to influence the grain forming processes in this variety. Anthesis was delayed in other sensitive varieties by about 5 days at late sowing when the mean temperature was within 23°C to 24°C which was higher than that of Sonora (Fig 1). Anyway this is not related to tolerance of in case of Sonora.

Results from other studies showed that number of grain per ear is determined during GS_2 phase (double ridge to anthesis) and it is the most sensitive stage. Heat stress in this stage decreases grain number per ear (Shpiler and Blum, 1986). In present experiment the plant under late sowing conditions were exposed to higher temperature during GS_2 phase compared to optimum sowing conditions. As a result late sowing gave reduced grain number compared to optimum sowing. Decreased number of grain per ear in different magnitude were observed by Islam *et al.* (1993), He and Rajaram (1993), Al-Khatib and Paulsen (1990), and Bhatta *et al.* (1994) under late sowing or high temperature conditions compared to optimum sowing temperature. These results are in agreement with those of present studies.

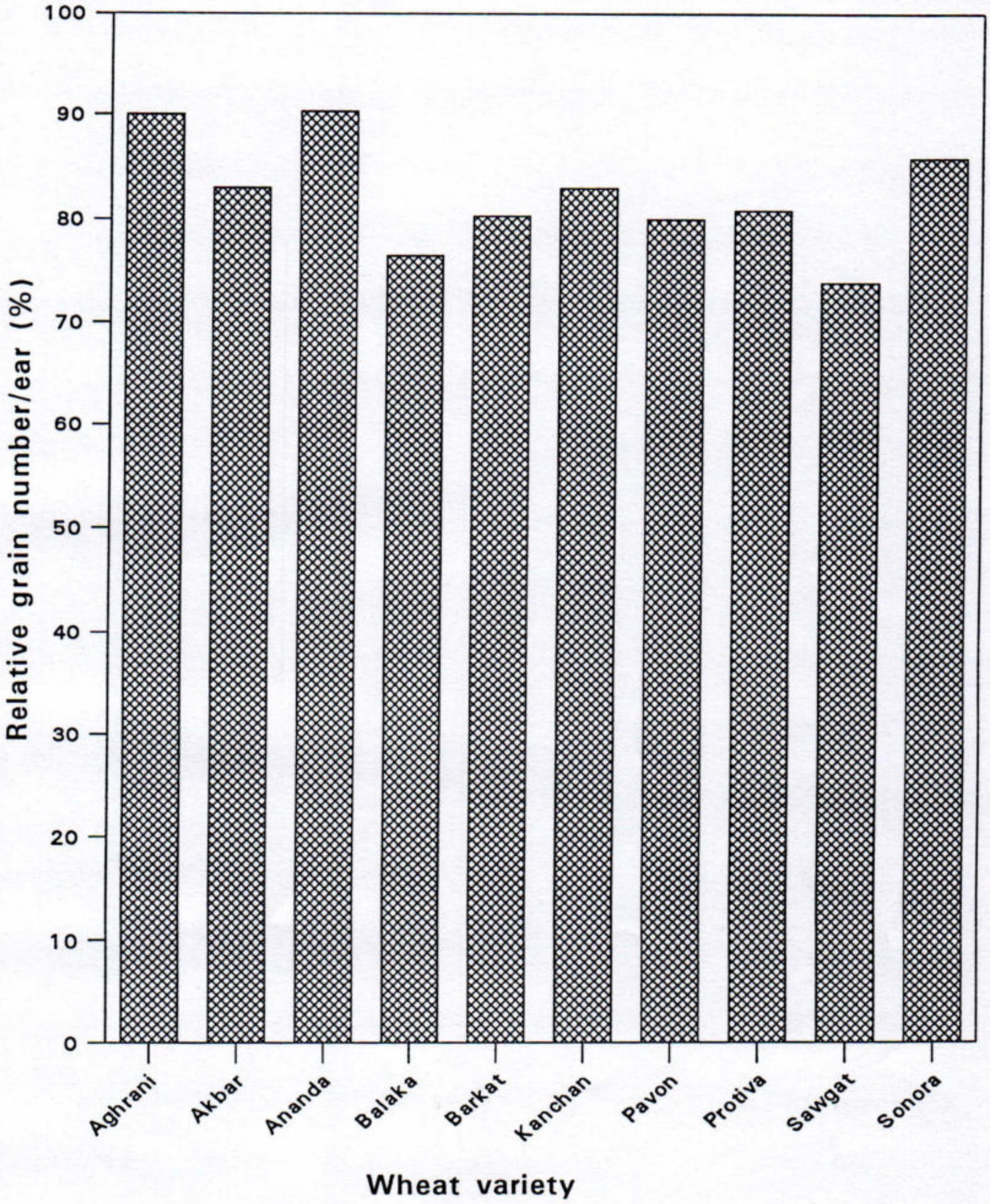

Fig.4 Relative grain number/ear (%) of different wheat varieties.

b. 1000 grain weight

The results showed that at November 30 (optimum sowing) variety Aghrani had the highest 1000 grain weight (44.06 g) which was at par with Sawgat, Akbar, Kanchan and Protiva whereas variety Sonora had the lowest 1000 grain weight (31.68 g) (Table 4). In December 30 sowing (late sowing) again variety Aghrani attained the highest grain weight (38.49 g) which was at par with Akbar, Kanchan and Protiva while the variety Sonora had the lowest grain weight (25.16 g).

Table 4. Weight (g) of 1000 grain of wheat as affected by interaction between sowing time and variety

Treatments	1000 grain weight (g)	
	November 30	December 30
Aghrani	44.06 a	38.49 c
Akbar	43.38 a	37.89 c
Ananda	39.02 bc	33.40 de
Balaka	40.45 b	32.05 e
Barkat	37.70 c	32.27 e
Kanchan	43.44 a	37.58 c
Pavon	32.74 de	27.04 f
Protiva	43.71 a	37.33 c
Sawgat	44.00 a	34.40 d
Sonora	31.68 e	25.16 g

Mean followed by the same letter(s) do not differ significantly at 1% level by DMRT.

At December 30 sowing all the tolerant and the sensitive varieties significantly reduced their 1000 grain weight compared to November 30 sowing. The significant interaction between sowing time and variety indicated that the magnitude of reduction in 1000 grain weight was different among the varieties. This difference amount of reduction in 1000 grain weight was due to differences in responses of wheat varieties to sowing time. Tolerant and moderately tolerant varieties viz. Aghrani, Ananda, Barkat, Pavon, Akbar, Kanchan and Protiva showed 87.35%, 85.60%, 85.60%, 82.59%, 87.34%, 86.51% and 85.40% relative 1000 grain weight respectively, whereas heat sensitive varieties Balaka, Sawgat and Sonora showed 79.23, 78.18 and 79.42% relative grain weight respectively (Fig. 5). Maximum relative grain weight (>82%) in varieties Aghrani, Akbar, Ananda, Barkat, Kanchan, Pavon and Protiva was due to their relative heat tolerance. The minimum relative grain weight (<80%) in varieties Balaka, Sawgat and Sonora indicated their sensitivity to late sowing high temperature conditions.

Under late sowing conditions the plant experienced high temperature during grain filling period. Tashiro and Wardlaw (1989) reported that net effect of heat stress in this period is lower grain weight due to reduction in grain filling period, grain filing rate or the combined effect of both. Also late sowing or heat stress conditions reduced grain weight (compared to optimum sowing time or optimum temperature) was reported by Islam *et al.* (1993), Shukla *et al.* (1992), He and Rajaram (1993), Asana and Williams (1965), Asana and Saini (1962), Chinoy (1947), Al-khatib and Paulsen (1990), and Bhatta *et al.* (1994) in different wheat genotypes or varieties. Genotypic differences in relative grain weight were reported by different authors (Al-khatib and Paulsen 1990; and

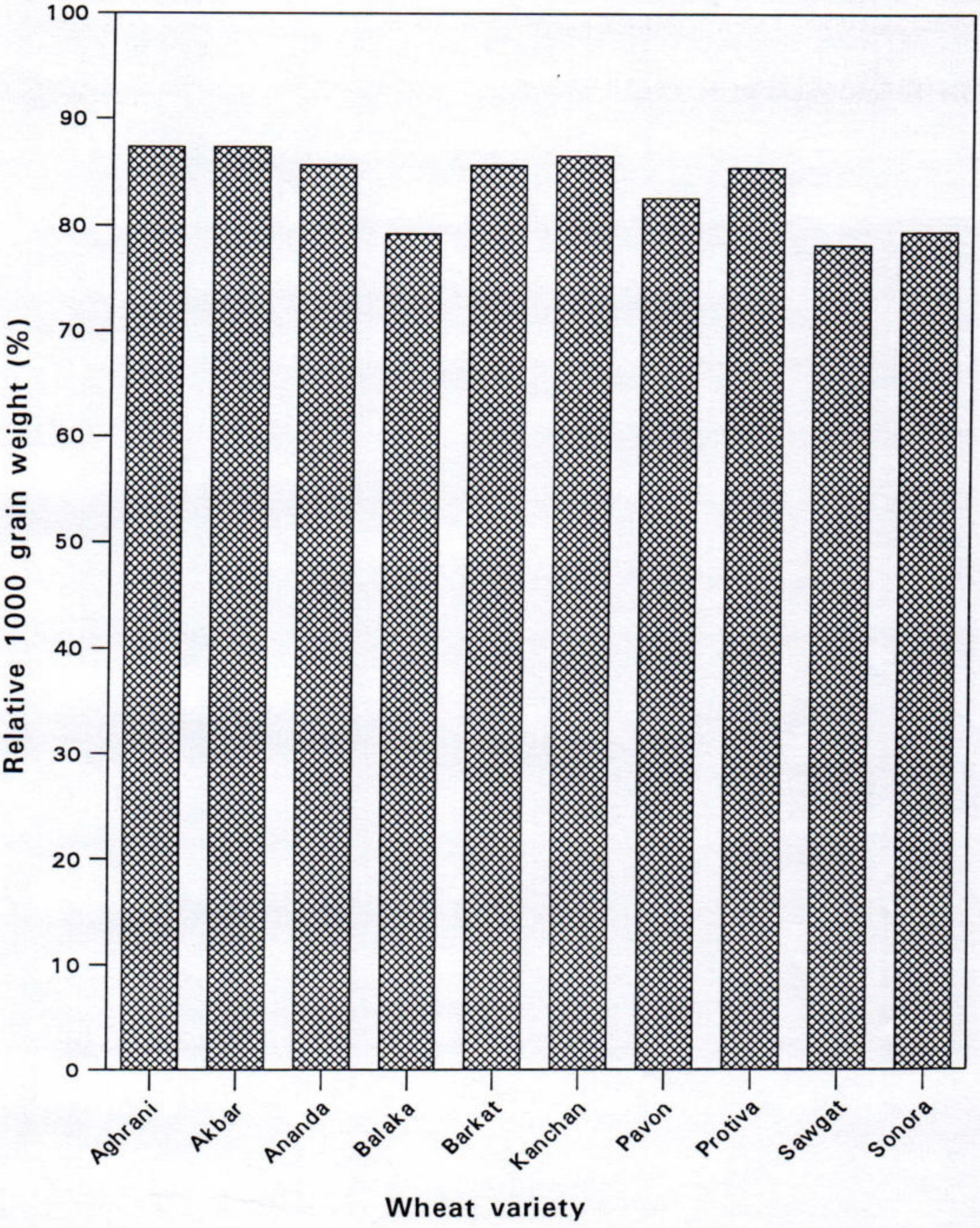

Fig.5 Relative 1000 grain weight (%) of different wheat varieties.

Asana and Saini 1962). Grain size is a very stable character for all varieties of wheat to the developmental and synthetic activity of the grain as an important determinant of grain yield (Asana and Williams (1965). Al-khatib and paulsen concluded that high relative grain weight as a potential selection criteria of high temperature tolerant genotypes. All these findings support the results of the present experiment.

c. Grain weight (g) per main-shoot ear

At November 30 sowing (optimum sowing), the variety Aghrani had the highest grain weight (2.47 g) per main shoot ear. The lowest grain weight (1.64 g) of main shoot was obtained by Ananda which was at par with Balaka (1.72 g), Pavon (1.70 g) and Protiva (1.76 g) (Table 5). In December 30 sowing (late sowing), again the variety Aghrani obtained the highest grain weight (2.0 g) per main shoot ear whereas the variety Balaka attained the lowest grain weight (1.19 g) per main shoot ear.

At December 30 sowing both the tolerant and sensitive varieties significantly reduced their grain weight of main shoot ear compared to November 30 sowing. The relative weight in grain per main shoot ear of different varieties were different, which indicated that responses of wheat varieties to sowing time were different.

Table 5. Grain weight (g) per main shoot ear of wheat as affected by the interaction between sowing time and variety

Treatments	Grain weight (g) of main shoot ear	
	November 30	December 30
Aghrani	2.47 a	2.0 c
Akbar	2.17 b	1.72 fg
Ananda	1.64 g	1.34 h
Balaka	1.72 fg	1.19 i
Barkat	1.81 d-f	1.31 hi
Kanchan	1.85 de	1.31 hi
Pavon	1.70 fg	1.20 i
Protiva	1.76 e-g	1.30 hi
Sawgat	1.92 cd	1.32 hi
Sonora	1.81 d-f	1.23 hi

Mean followed by the same letter(s) do not differ significantly at 5% level by DMRT.

Heat tolerant and moderately tolerant varieties viz. Aghrani, Ananda, Barkat, Pavon, Akbar, Kanchan and Protiva showed 80.97%, 81.71%, 72.37%, 70.59%, 79.26%, 70.81% and 73.86% relative grain weight per main shoot ear respectively (Fig. 6). Higher relative grain weight per main shoot ear (>70%) in the varieties- Aghrani, Akbar, Ananda, Barkat, Kanchan, Pavon and Protiva indicated their relative tolerance. The lower relative grain weight per main shoot ear in (<70%) the varieties- Balaka, Sawgat and Sonora indicated their sensitivity to late sowing time.

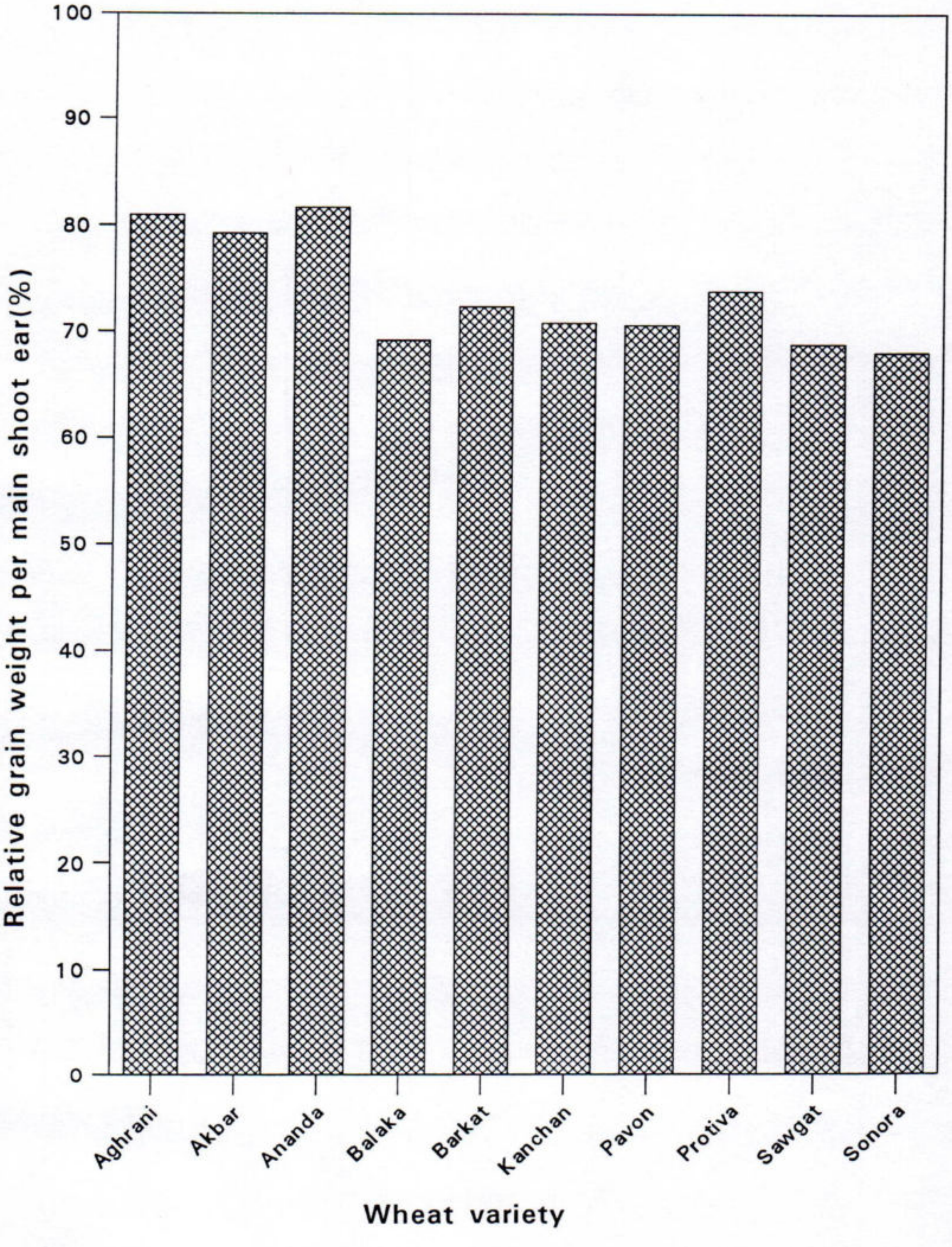

Fig.6 **Relative grain weight per main shoot ear(%) of different wheat varieties.**

Results of Asana and Williams (1965) showed that grain weights per main shoot ear were decreased in all cultivars of wheat at high temperature compared to optimum temperature. But the amount of decrease were different among the cultivars and some cultivars showed higher relative grain weight per main shoot ear compared to other cultivars. These findings support the present study.

d. Number of ear per plant

Ear number per plant was significantly influenced by the interaction effects of sowing time and variety (Table 6). At November 30 sowing (optimum sowing) the varieties- Ananda and Barkat had the highest ear number par plant (9.35) which was at par with Pavon (9.20) and Protiva (9.10) whereas variety Akbar had the lowest ear number per plant (6.15). In December 30 sowing (late sowing) the variety- Pavon attained the highest ear number per plant (7.5) which was at par with Ananda, Kanchan and Sawgat while the variety Akbar had the lowest ear number per plant (4.35).

Table 6. Ear number per plant of wheat as affected by interaction between sowing time and variety

Treatments	Ear number per plant	
	November 30	December 30
Aghrani	6.25 h	4.85 i
Akbar	6.15 h	4.35 i
Ananda	9.35 a	7.4 c-e
Balaka	8.05 bc	6.45 f-h
Barkat	9.35 a	6.45 f-h
Kanchan	8.20 bc	7.2 d-f
Pavon	9.20 a	7.5 b-d
Protiva	9.10 a	6.35 gh
Sawgat	8.30 b	6.85 d-h
Sonora	7.15 d-g	6.2 h

Mean followed by the same letter(s) do not differ significantly at 5% level by DMRT.

At December 30 sowing (late) all the tolerant and the sensitive varieties significantly reduced their ear number per plant compared to November 30 sowing (optimum). The significant interaction between sowing time and variety indicated the magnitude of reduction in ear number per plant was different among the varieties which were due to differences in responses of wheat varieties to sowing time. Relative ear number per plant was lowest in tolerant variety Barkat (68.98%) and moderately tolerant varieties Akbar (70.73%) and Protiva (69.78%) (Fig. 7). Irrespective of heat tolerance the relative ear number per plant was higher in the remaining varieties- Aghrani (77.6%), Ananda (79.14%), Balaka (80.12%), Kanchan (87.80%), Pavon (81.52%), Sawgat

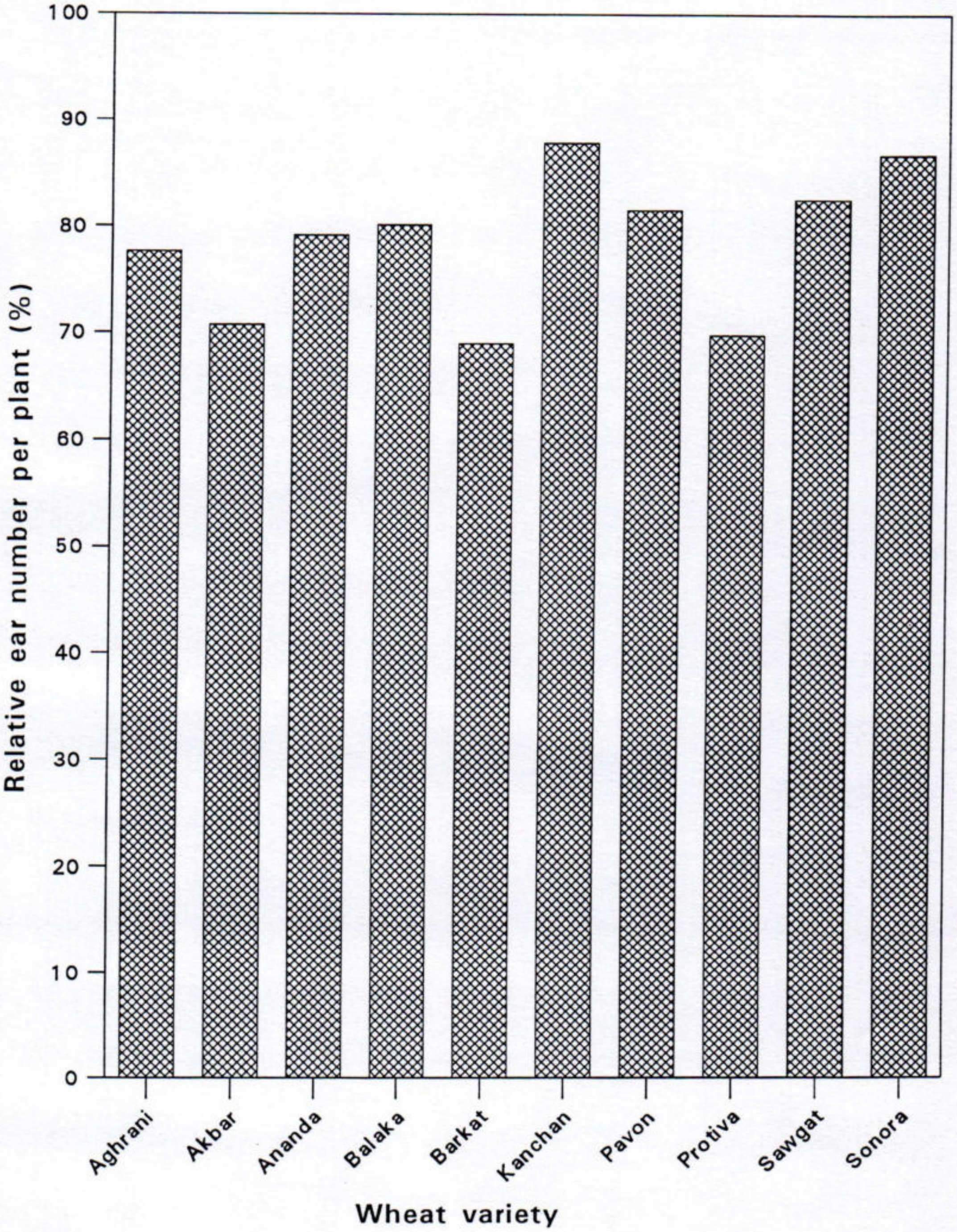

Fig.7 Relative ear number per plant(%) of different wheat varieties.

(82.53%) and Sonora (86.71%). Unlike other yield components (grain number / ear, 1000 grain wt. and main short grain weight) in this study the ear number per plant was not influenced by sowing time. Ear number per plant is decided by the effective tiller number per plant. The varietal differences in reduction of effective tiller number per plant can not be explained clearly from the results of the present experiment. So, the influence of temperature on tillering process and subsequently on tiller survival mechanism needs further experimentation for confirmation.

Results from other studies showed that late sowing causes reduced ear number per square meter and the amount of reduction was different in different varieties of wheat (Islam *et al.*, 1993). He and Rajaram (1993) reported that ear number per square meter is less heat sensitive while yield, grains per ear, biomass and plant height are more heat sensitive. Shanahan *et al.* (1990) mentioned that heat tolerant genotypes was associated with productivity only under more extreme temperatures. These findings partially support the present experiment.

e. Grain yield

Sowing time and variety interacted significantly to influence the grain yield (Table 7). At November 30 sowing (optimum sowing) the tolerant variety Barkat attained the highest yield (4.52 tha^{-1}) which was followed by Protiva, Kanchan, Ananda and Aghrani. The heat sensitive variety Sonora gave the lowest yield (2.85 tha^{-1}).

At December 30 sowing (late sowing) the moderately tolerant variety Kanchan obtained the highest yield (2.15 tha^{-1}). Which was at par with Aghrani, Ananda, Barkat, Pavon and Sawgat. But the variety Sonora produced the lowest yield (1.45 tha^{-1}).

Table 7. Grain yield of wheat as affected by the interaction between sowing time and variety

Treatments	Grain yield (tha^{-1})	
	November 30	December 30
Aghrani	3.7 bc	1.94 gh
Akbar	3.61 cd	1.64 hi
Ananda	3.99 bc	1.95 gh
Balaka	3.31 de	1.67 hi
Barkat	4.52 a	1.83 g-i
Kanchan	3.8 bc	2.51 g
Pavon	3.2 ef	1.90 g-i
Protiva	4.05 b	1.52 i
Sawgat	3.61 cd	1.94 gh
Sonora	2.85 g	1.45 i

Mean followed by the same letter(s) do not differ significantly at 1% level by DMRT.

Both tolerant and sensitive varieties significantly reduced grain yield at December 30 sowing compared to November 30 sowing. But the magnitude of reduction was different among the varieties. This was because that the response of wheat varieties to sowing time was different. The tolerant variety Pavon showed the highest relative grain yield (59.37%) (Fig. 8) whereas some other varieties- Aghrani (tolerant) and Kanchan (moderately tolerant) gave 52.43% and 56.58% relative grain yield respectively. The relative grain yield of the tolerant variety Barkat was 40.48% and in moderately tolerant

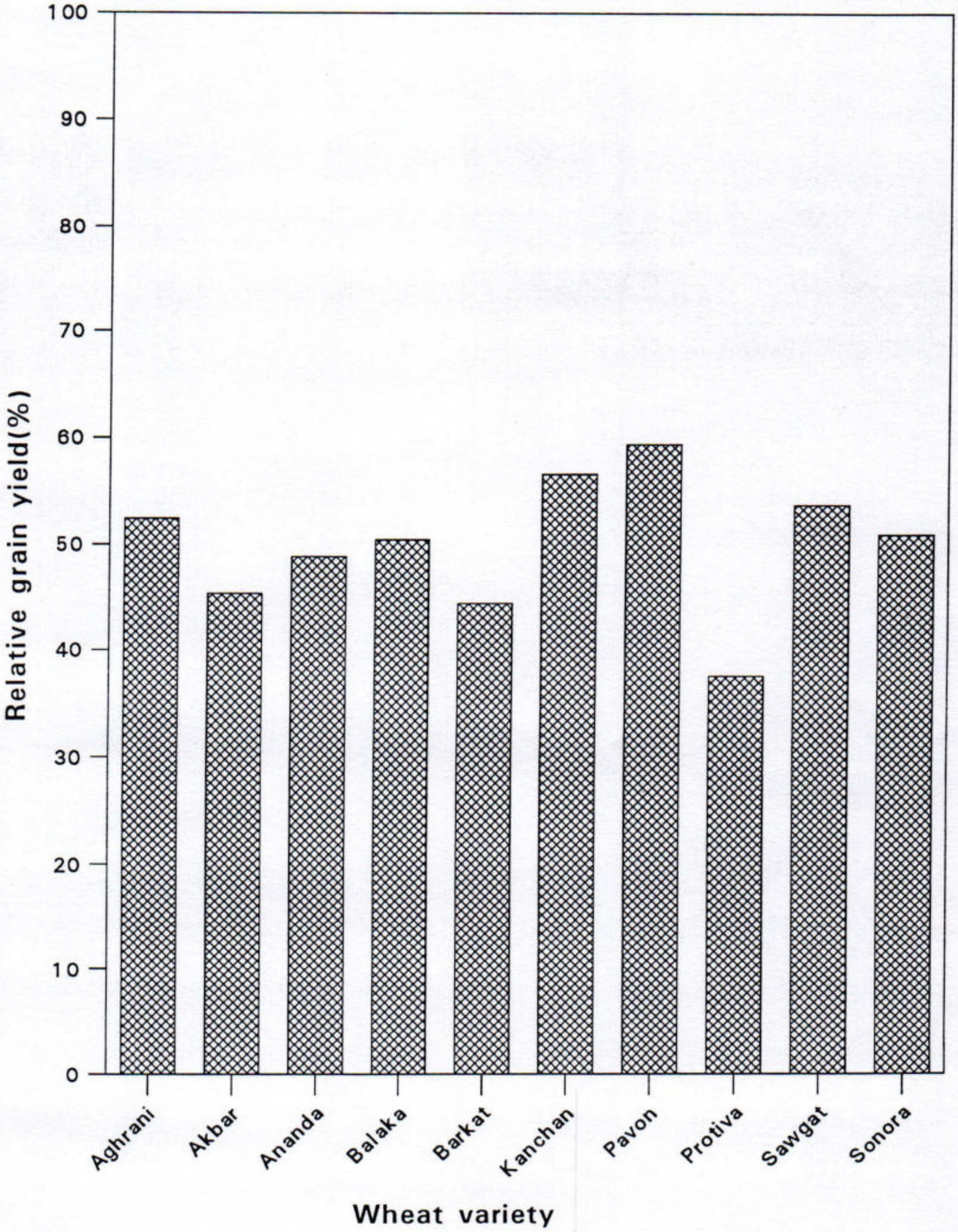

Fig.8 Relative grain yield(%) of different wheat varieties.

varieties it was ranged from 37.53% in Protiva to 45.43% in Akbar. The relative yield of Barkat, Protiva and Akbar were considered as poor relative yield in comparison to other varieties in which relative yield was high enough and ranged from 50.45% in Balaka to 53.~~37~~74% in Sawgat except Ananda. Ananda had a relative yield of 48.87% and this was considered as intermediate. The varieties having intermediate to poor relative yield could be due to loss of high percentage of ear number per plant in late sowing in comparison to optimum sowing time. Being heat sensitive variety Balaka, Sawgat and Sonora had high relative yield of 50.45%, 53.74% and 50.87% respectively. Such high relative yield of sensitive varieties were apparently due to their high relative ear number per plant. The yield (t/h) is not only the outcome of tolerance, it rather depends on some other factors those influence the formation of yield components.

Results from other studies showed that late sowing causes lower grain yield of wheat genotypes compared to optimum sowing (Islam *et al.*, 1993, Bhatta *et al.,* 1994, and Kanani and Jadon, 1985). Bhatta *et al.* (1994) reported that some genotypes of wheat showed stability of grain yield between optimum and late planting. Numerous researchers also found reduced grain yield at high temperature stress conditions compared to optimum temperature (Acevedo *et al.*, 1991; Al-khatib and Paulsen, 1990; Asana and Williams, 1962; He and Rajaram, 1993 and Ahmed *et al.*, 1989). Al-khatib and Paulsen (1990) concluded that high relative grain yield which are the result of stable and/or long durations of photosynthetic activity at heat stress conditions is a selection criteria of heat tolerance of wheat genotypes. Shanahan *et al.* (1990) observed that heat tolerance genotypes were associated with productivity only under more extreme temperatures and did not always give high yield at any environment. The results of present study are in agreement with the results of above related works.

CHAPTER V

GENERAL DISCUSSION

The longer heat killing time in membrane thermostability test indicates the relative heat tolerant of wheat varieties- Ananda, Pavon, Aghrani and Barkat. Shorter heat killing time indicates the relative heat sensitively in wheat varieties- Balaka, Sawgat and Sonora whereas the varieties- Akbar, Kanchan and Protiva with an intermediate heat killing time were considered as moderately heat tolerant. The longer heat killing time was due to more stable membrane system under high temperature conditions maintaining longer period of more or less normal activity. The normal membrane activity of tolerant varieties under high temperature was due to lower electrolyte leakage compared to the electrolyte leakage in sensitive varieties.

In the present experiment heat tolerant varieties gave higher relative grain number, relative 1000 grain weight, relative main shoot grain weight and also longer grain filling period with high growth rate compared to heat sensitive varieties. But heat tolerant varieties showed a decreased stem reserve translocation to the final grain weight under late seeded warmer conditions. Stem reserve translocation, however, was increased in heat sensitive varieties. Increased stem translocation have also been reported under stressful environment (Gallagher *et al.*, 1976). This was because of reduction of photosynthesis to a level which fail to fulfil the demand of assimilates in developing grain from current photosynthesis. Results of the present experiment, therefore, suggest that the tolerant varieties apparently were able to fulfil the assimilates demand from current photosynthesis to the developing grain. There are reports of almost unaffected thylakoid activity in heat tolerant wheat varieties for a longer period compared to sensitive varieties (Al-Khatib and Paulsen, 1990). The findings of Al-Khatib and Paulsen (1990) support the results of less stem reserve translocation in grain development in heat tolerant varieties. The results also apparently suggest that the stable rate and longer duration of photosynthesis in tolerant wheat varieties were responsible for relatively high grain growth duration and rate, high relative 1000 grain weight as well as high relative main shoot grain yield.

Higher relative grain number per ear under late seeded warmer conditions in heat tolerant varieties could be due to less sterility of florets under warmer conditions. Sonora, a heat sensitive variety also gave high relative grain number per ear under late seeding conditions. This could be due to early anthesis of the variety escaping high temperature at anthesis. Perhaps it could not be related to high temperature tolerance.

The relative ear number per plant of the tolerant variety Barkat and moderately tolerant varieties Akbar and Protiva were not higher compared to the sensitive varieties like Balaka, Sawgat and sonora. Ear number per plant was governed by effective tiller number per plant. In the present experiment the tillering was completed with a mean temperature not exceeding 20°C (Figure 9). Acevedo *et al.* (1991) reported that temperature between 16-20°C did not affect the tillering process adversely. So the prevailing temperature during tillering was not high enough to be stressful on ear number per plant. As such, the temperature after completion of maximum tillering mainly affected the ear number per plant under late sowing conditions. Because in course of

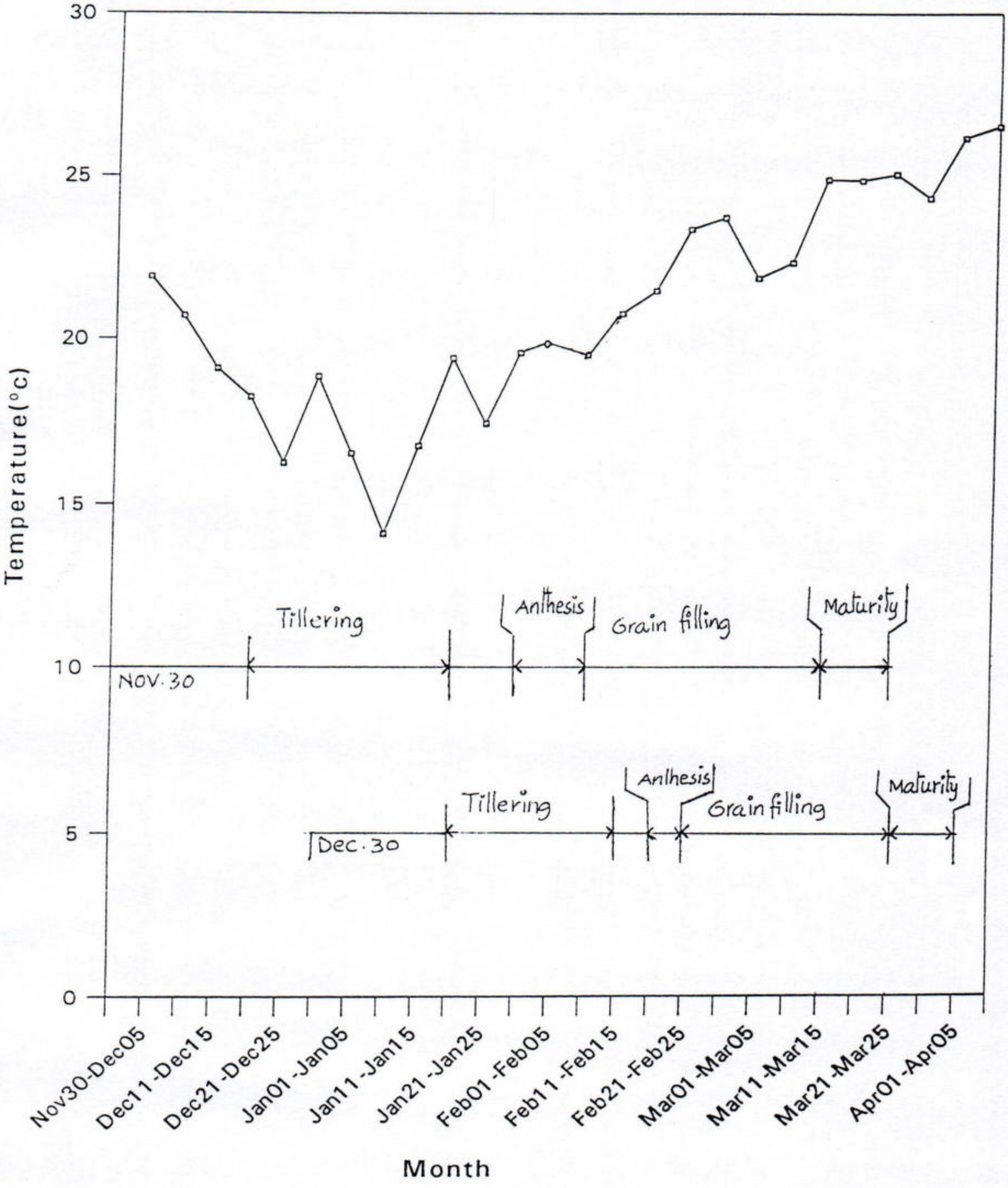

Fig.9 Mean air temperature(°c) during wheat growing period.

development some tillers die at different stages of growth. Moreover, all survived tillers may not bear ear. From the results of the present experiment, the survival of tillers and their ear bearing capacity could not be explained clearly. Further investigations could be done in this regard. Among the yield components ear number per plant is one of the most dominant parameter. High relative ear number per plant under warmer conditions in sensitive varieties could be explained by minimum tiller death or maximum effective tiller producing capacity. As a result, the heat sensitive varieties gave high relative grain yield which was almost similar to those of some tolerant varieties.

The overall results of this experiment suggest that the grain yield is the ultimate outcome of several interrelated morphophysiological parameters in addition to genetic make up of the varieties. These parameters influence the yield component and finally the grain yield.

CHAPTER VI

SUMMARY AND CONCLUSION

An experiment was conducted at the Bangabandhu Sheikh Mujibur Rahman Agricultural University, Salna, Gazipur, during November 1997 to April 1998 to study the relative tolerance in ten recommended wheat varieties with respect to their relative performance under late sowing warmer conditions. The varieties- Aghrani, Akbar, Ananda, Balaka, Kanchan, Pavon, Protiva, Sawgat and Sonora were used as study material. The seeds of these ten varieties were sown in November 30 and December 30. November 30 was regarded as optimum sowing time whereas December 30 was late sowing time.

Through membrane thermostability test the relative heat tolerance of these wheat varieties were determined. Based on heat killing time the varieties- Aghrani, Ananda, Barkat and Pavon were considered as relatively heat tolerant (210 to 240 minutes) whereas the varieties- Akbar, Kanchan and Protiva were moderately heat tolerance (120 to 150 minutes) and the varieties- Balaka, Sawgat and Sonora were regarded as heat sensitive (60 to 90 minutes).

Grain growth pattern was observed in one relatively heat tolerant variety, Aghrani and heat sensitive variety Sonora. At November 30 sowing both heat tolerant (Aghrani) and heat sensitive (Sonora) varieties attained their physiological maturity at 40 DAA. But in general, Aghrani had higher growth rate than Sonora. At December 30 sowing the varieties Aghrani and Sonora attained physiological maturity at 32 DAA and 28 DAA respectively. In late sowing, the tolerant variety Aghrani maintained a higher grain growth rate for longer period compared to sensitive variety Sonora. The tolerant variety Aghrani maintained a growth rate of more than 1 mg/day/grain for a period of 0 to 24 DAA in which Sonora maintained the same rate from 9 to 20 DAA.

All tolerant and moderately tolerant varieties reduced their pre-anthesis stem contribution towards the final grain weight whereas all sensitive varieties increased it at late sowing (December 30) high temperature conditions.

In yield parameters, grain number per ear, 1000 grain weight and grain weight per main shoot were significantly reduced in December 30 sowing compared to November 30 sowing. But relatively heat tolerant and moderately heat tolerant varieties viz., Aghrani, Ananda, Barkat, Pavon, Akbar, Kanchan and Protiva showed a higher relative performance of those parameters compared to heat sensitive varieties Balaka, Sawgat and Sonora.

The number of ear per plant was significantly reduced in December 30 sowing. But the relative ear number per plant was lower in tolerant variety Barkat (68.98%) and moderately tolerant varieties Akbar (70.73%) and Protiva (69.78%). The remaining seven varieties viz., Aghrani, Ananda, Balaka, Kanchan, Pavon, Sawgat and Sonora had high relative ear number per plant from a range of 77.6% to 87.80% irrespective of heat tolerance.

The response of grain yield of wheat varieties to sowing time was different than other parameters. Relatively heat tolerant varieties Pavon and Aghrani and moderately tolerant variety Kanchan showed higher relative yield with a range from 52.43% to

59.37%. But the relatively heat sensitive varieties Balaka, Sawgat and Sonora attained also high relative grain yield ranging from 50.45% to 53.37%. Among the remaining varieties tolerant Barkat, and moderately tolerant Protiva and Akbar showed comparatively lower relative grain yield (37.53% to 45.43%).

From the results finally it might be concluded that in addition to membrane thermostability test the long grain filling period with high grain filling rate were the indicators of tolerance in wheat to late sowing high temperature conditions. But the heat tolerant varieties showed less stem reserves translocation at late sowing. The tolerant varieties also gave high relative grain number per ear, 1000 grain weight and main shoot grain weight. These parameters can also be used to indicate high temperature tolerance induced by late sowing conditions. But the heat tolerant and sensitive varieties showed inconsistent results in relative ear number per plant and relative grain yield.

The results also lead to understand that a heat tolerant high yielding variety can be developed through combining high relative ear number per plant and heat tolerance characters. However, further investigation are needed for confirmation of present experimental findings.

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APPENDICES

Appendix 1. Comparative food value (in edible portion) of wheat and rice

Parameters	Wheat (250 g)	Rice (250 g)
Energy (Cal.)	900.00	865.00
Carbohydrate (g)	174.00	198.00
protein (g)	30.00	16.00
Fat (g)	4.30	1.00
Fibre (g)	4.80	0.50
Minerals (g)	6.80	1.80
Calcium (g)	120.00	23.00
Phosphorus (mg)	1065.00	385.00
Iron (mg)	8.00	8.00
Vitamin-A (mg)	73.00	0.00
Thiamin (μg)	1.23	0.50
Riboflavin (μg)	0.73	0.50
Niacin (mg)	11.00	10.00

Source : Wheat Research Centre, Nashipur, Dinajpur, Bangladesh

Appendix 2. Initial physio-chemical properties of experimental plot soil

Soil depth (cm)	Particle size distribution (%)			Texture	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	pH	Organic carbon (%)	Total nitrogen (%)
	Sand	Silt	Clay						
0-5	12.0	46.0	42.0	Sic	1.62	2.59	5.6	0.42	0.030
10-15	17.0	45.0	38.0	Sicl	1.61	2.59	5.4	0.38	0.025
20-25	15.0	47.0	38.0	Sicl	1.56	2.68	5.3	0.27	0.025

* Sic = Silty clay

* Sicl= Silty clay loam

Source : Adopted from a thesis by Kamrun Nahar, Department of Soil Science, BSMRAU, Gazipur-1703, Bangladesh.

Appendix 3. Air temperature, relative humidity and rainfall during the growing period of wheat

Month		Mean air temperature (°C)		Relative humidity (%)		Total rainfall (mm)
		Max.	Min.	Max.	Min.	
December '98	1[*]	26.00	16.62	83.10	67.80	21.8
	2	23.05	14.29	89.10	66.40	0
	3	23.67	11.68	85.45	61.45	0
January '98	1	18.94	11.68	87.80	78.90	0
	2	23.93	12.23	82.90	57.20	23.0
	3	23.29	13.51	80.90	61.70	9.4
February '98	1	26.01	13.39	76.80	52.40	0
	2	27.26	15.74	78.00	52.60	1.0
	3	28.84	18.25	72.62	56.14	1.0
March '98	1	28.60	15.61	64.90	43.10	7.6
	2	31.24	18.30	71.20	47.00	18.4
	3	29.76	19.44	74.54	57.36	15.2
April '98	1	31.93	20.78	75.30	48.70	31.2

[*] 1 Stands for day 01 to day 10, 2 for day 11 to 20, 3 for 21 to end of a month.

Source : Plant Physiology Division, Bangladesh Rice Research Institute, Gazipur-1701.

Appendix 4. Developing grain dry weight (mg/grain) of wheat from anthesis to maturity

Variety	Days after anthesis																					
	4		8		12		16		20		24		28		32		36		40		44	
	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30	Nov. 30	Dec. 30
Akbar	5.43	3.38	11.17	8.47	19.67	15.88	30.98	22.11	39.76	32.90	42.91	37.14	43.81	38.16	44.46	38.42	44.76	38.43	44.90		44.91	
Ananda	6.04	4.50	12.63	8.28	23.44	16.74	29.51	21.92	34.24	26.30	39.82	31.45	40.83	32.50	41.25	33.05	41.50	33.06	41.62		41.62	
Balaka	3.81	3.75	10.52	6.98	17.19	13.15	28.17	22.95	35.23	29.19	37.97	31.52	39.14	32.10	39.88	32.11	40.37	32.11	40.67		40.67	
Barkat	3.80	3.14	9.77	6.11	18.31	12.84	26.11	19.60	33.86	25.07	36.60	30.48	37.52	31.51	38.15	32.18	38.97	32.19	39.69		39.68	
Kanchan	4.48	3.23	10.60	7.69	18.18	16.4	25.18	23.23	36.37	30.65	42.23	34.10	44.19	36.24	44.78	37.50	45.29	37.51	45.69		45.67	
Pavon	3.92	2.01	9.50	5.84	15.63	9.37	21.44	17.48	28.01	24.21	31.23	27.78	32.52	28.21	33.10	28.40	33.58	28.41	33.84		33.84	
Protiva	4.77	2.67	10.10	7.91	18.67	15.10	27.07	24.91	36.60	31.17	39.92	34.14	43.88	36.39	44.45	37.30	44.75	37.30	44.90		44.89	
Sawgat	4.70	2.52	11.72	7.70	18.34	14.90	28.88	24.01	34.54	31.20	41.23	33.65	42.85	34.40	43.25	34.41	43.60	34.40	43.76		43.75	