

**AN APPROACH OF DEVELOPING PRODUCTION TECHNOLOGY
OF DISEASE FREE QUALITY SEED POTATO**

**A DISSERTATION
BY
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**DOCTOR OF PHILOSOPHY
IN
PLANT PATOLOGY**



**DEPARTMENT OF PLANT PATHOLOGY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
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**Submitted to
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in partial fulfillment of the requirements for the degree of**

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SEPTEMBER 2019

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TO

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DECLARATION

Muhammad Shamsul Huda, hereby declared that the dissertation title “AN APPROACH OF DEVELOPING PRODUCTION TECHNOLOGY OF DISEASE FREE QUALITY SEED POTATO” submitted to the Department of plant Pathology, Hajee Mohammad Danesh Science and Technology University, Dinajpur, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in plant pathology is a record of bona-fide research designed and carried out by me. No part of this dissertation was produced elsewhere for any degree. it does not contain any collaborate study.

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CERTIFICATE

This is to certify that the work embodied in this dissertation is an original research work done by Muhammad Shamsul Huda under my supervision for the degree of Doctor of Philosophy in plant pathology. The references cited in it have duly been acknowledged. The style and content of the dissertation have approved and recommended for submission.

Professor Dr. Sheikh Md. Mobarak Hossain
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BIOGRAPHIC SKETCH

Muhammad Shamsul Huda son of Muhammad Jalal Uddin and Mrs. Rokeya Begum was born on 23 February, 1979 in Gazipur District of Bangladesh. He passed SSC and HSC examinations in 1993 and 1995, respectively from Dhaka Board. He obtained his B.Sc.Ag.(Hons.) degree from Bangladesh Agricultural University, Maymensingh, Bangladesh in 2000, the exam was held in 2003. He also obtained MS degree in Seed Science and Technology from Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh in Winter Term, 2012. He enrolled as a Ph.D. student in October 2014 in the Plant Pathology, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. He started his carrier as a Scientific Officer, Bangladesh Agricultural Research Institute from 2006. In 2015, he has been promoted to the position of Senior Scientific Officer of the same organization. He is happily married with Syeda Sabiha Zamal, Executive Engineer, Bangladesh Agricultural Development Corporation, and blessed with a son, Md. Shakhir Abdullah and a daughter Mss. Sumaia Iffat Iba.

ABSTRACT

The experiments were conducted at the research field and post graduate laboratory of Plant Pathology Department, HSTU, Dinajpur, during November 2014 to march 2018 to improve the technique of low-cost disease free potato seed production protocol. Farm saved seed was compared with certified seed, positive selection seed, seed plot technique's seed and TLS seeds potato in 1st experiment. The different seed planting time of 15th October, 4th November, 24th November and 14th December and different Haulm pulling time at 68, 75, 82 and 89 DAP were evaluated in 2nd experiment. The different size of mother seed tuber like $S_1 = 15$ to 25 mm, $S_2 = 25$ to 35 mm, $S_3 = 35$ to 45 mm and $S_4 = 45$ to 55 mm diameter with different concentration of gibberellic acid (GA_3) like $G_{00} = 00$ ppm, $G_{20} = 20$ ppm, $G_{40} = 40$ ppm, $G_{60} = 60$ ppm were used to evaluate in 3rd experiment. The four different categories of seed potato viz. Minutuber, Breeder seed, Foundation seed and Certified seed were used to advance generation in 4th experiment. In the 5th experiment 35 to 45 mm and 35 to 45 mm seed tuber with the haulm pulling at 75, 82, 89, 96 and 103 days after planting (DAP) were evaluated to adjusting haulm pulling time for GA_3 treated seed tuber. The maximum yield (27.72 ton/ha) was recorded from Positive Selection's Seeds which was similar with Certified and Seeds of SPT. But, the maximum plants ($\geq 8\%$, 7.33 % and 4.17 %) were infected by PVY, PLRV and PMV respectively in Farmer's seed. 100% emergence was recorded from all planting time except 15 October. Maximum late blight (LB) infestation (2.90%) and LB severity i.e. PDI (21.81) was recorded in planting time of 24th November during 1st week of January 2017. At 60 DAP, maximum potato virus Y infected plants (2.08%) were identified from 24th November planting time which was followed by 4th November. At haulm pulling time, the highest percentage (9.38%) of PMV affected plants was counted from 24 November. The maximum infected plants (PRLV 3.13%, PMV 4.69% and PVY 2.6 %) were recorded from late haulm pulling (89 or 82 DAP). The maximum potato yield (29.23 ton/ha) and seed potato yield (23.87 ton/ha) were recorded from 24 November with HP 89 DAP and 4 November with 82 DAP, respectively. The highest (23.05) branch number of sprouts /tuber were recorded from S_4G_{40} . The maximum percentage of potato mosaic virus and potato leaf roll virus was found at G_{60} . The maximum and minimum percentage of potato leaf roll virus was found in S_1 and S_4 . The height (42.67 ton/ha) yield was recorded from S_4G_{60} which was similar with S_3G_{40} . In 1st, 2nd and 3rd generation, the maximum 0.46 %, 1.39 % and 5.56% plants were naturally infected by potato virus Y in certified seeds. The minimum 0%, 0% and 0.46% plants were naturally infected by potato virus Y in minutuber. Similar results were recorded for PLRV. The infestation of *Rhizoctonia* canker, common scab and deformed tuber of potato were also increased with increasing generation. In 1st generation, the highest healthy tuber yield (36.58 ton/ha) was recorded from breeder seed. In 2nd and 3rd generation, the highest healthy tuber (36.39 ton /ha and 32.85 ton/ha) was found from progeny of minutuber. But increasing generation decrease the healthy tuber yield except minutuber (7.06% increase in 2nd generation). The maximum infected plants ((PMV 3.70%, PVY 2.78 % and PRLV 4.32 %,) were recorded from late haulm pulling (103 DAP). The maximum seed potato yield (29.28 ton/ha) was recorded from 96 DAP haulm killing which was similar with 89 and 103 DAP haulm killing. The highest benefit-cost ratio was observed in of 35 - 45 mm mother seed (40 ppm GA_3 treated) with haulm pulling at 96 DAP (2.83). For seed potato production, best planting time is 1st week of November and haulm pulling at 75 to 82 DAP in conventional system. But by using 40 ppm GA_3 in mother seed tuber with haulm pulling at 89 DAP is suitable and profitable for seed potato production. Farm saved seed should be avoided and increasing generation of seed potato decrease the yield of seed potato.

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ACRONYMS AND ABBREVIATIONS

Acronyms	Abbreviations
BADC	: Bangladesh Agricultural Development Corporation
BARI	: Bangladesh Agricultural Research Institute
BSMRAU	: Bangabandhu Sheikh Mujibur Rahman Agricultural University
BS	: Black Scurf
CS	: Common Scab
DAP	: Days After Planting
ELISA	: Enzyme-Linked Immunosorbent Assay
GA	: Gibberellic Acid
HP	: Haulm Pulling
HSTU	: Hajee Mohammad Danesh Science And Technology University
LAC	: Leaf Area Coverage
LB	: Late Blight
PLRV	: Potato Leaf Roll Virus
PMV	: Potato Mosaic Virus
ppm	: parts per million
PVY	: Potato Virus Y
PDI	: Percent Disease Index
TCRC	: Tuber Crops Research Institute
RC	: <i>Rhizoctonia</i> Canker
SPT	: Seed Plot Technique

CHAPTER 1

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important food plant in the world (Braun, 2010). In terms of human consumption, it is the third most important non-grain food crop in the world after rice and wheat (CIP, 2017) and over half of all production occurs in developing countries (Devaux *et al.*, 2014). It is also the 3rd most crucial food crop of Bangladesh; it is mainly used as a vegetable crop. The increasing need for food created by world population growth has been contributed to meeting by Potato cultivation. Potato tubers accumulate large amounts of starch and are low in fat, and also contain proteins. In addition, potatoes contain vitamin C (Rodríguez-Falcón *et al.*, 2006). The developing countries are increasingly adopting potato cultivation primarily as food crop (Naik and Karihaloo, 2007). “Total area under potato crop has been estimated 4,75,488 hectares at 2016 compared to 4,71,013 hectares of the last (2015) year. Average yield rate of potato has been estimated 19.925 metric tons per hectare compared to 19.648 metric tons per hectare of previous year” (BBS_a, 2017). The total potato cultivated area was 3.13% in Bangladesh at 2015-16 (BBS_b 2017).

Potato being a vegetatively propagated crop provides ample opportunity for the pathogen to perpetuate from one generation to another through tubers and because of its succulence it prevents desiccation of the pathogens. Conventional methods of seed potato production involve the use of potatoes that are propagated by harvesting and replanting the tubers in the field. It is one of the slowest methods of seed multiplication. In modern system, the first multiplication steps in seed production programs are speeded up by using *in vitro* plantlets or microtubers (Bizarri and Ranalli, 1995). Mini-tubers are the progeny tubers produced on *in vitro* derived plantlets (Struik, 2007). The nucleus seeds or 1st generation seed (G₁) or minitubers of potato are usually produced from *in vitro* plantlets (Hussey and Stacey 1981). The tubers used for planting are known as “seed potatoes”, as opposed to “potato seeds” (Lemma Tessema *et. al.*, 2018).

All modern seed potato certification schemes are based on a ‘flow through’ principle in which material of high health status, generation zero (G₀), enters the top end of the seed scheme as microtubers or plantlets produced in accredited laboratories from pathogen-tested tissue culture stocks. After a limited number of field multiplications or generations, certified seed passes out the ‘bottom end’ of the scheme. In Bangladesh, certified seed potatoes are produced over a maximum of three field generations. Costly G₁ (minituber) seed produces generation one (G₂,

breeder seed) seed. Next year less costly G₂ seed is multiplied to produce G₃ (foundation) seed. In the third year, G₃ seed is multiplied to produce G₄ (certified) seed which is affordable enough to purchase by growers. So, the chain of seed potato in Bangladesh is as minituber (G₁) → Breeder seed (G₂) → Foundation seed (G₃) → Certified Seed (G₄) (Seed potato). One minituber of G₁ could be expected to produce 1kg of G₂ seed, with subsequent generations increasing 15-fold per generation to give 15 kg of G₃, 225 kg of G₄. For these reason, the cost of certified seed is very high (Anonymous, 2014).

Bangladesh imported elite class (E-class) seed potatoes from Holland at the cost of above US \$ 140.00 per quintal which engross or spends large amount of foreign currency every year (Anon, 2008). Bangladesh Agricultural Development Corporation (BADC) produce foundation seed potatoes using the E-class seed imported from Holland. Certified seed potatoes are produced from these foundation seed potatoes through contract growers under the supervision of BADC experts. Certified seed potatoes are distributed to the farmers for potato cultivation throughout Bangladesh (Karimb *et al.*, 2010). Only 10% quality seed potato of the total requirement is supplied by Government and private sectors. The remaining 90% requirement is mitigated by the farmers' retained seed which is usually of poor quality (Kabir and Haque, 2012).

The success of certified seed in developed countries has concentrated the research and development agenda, which is also essential in developing countries to establish the similar success. In most developing countries, the certified seed has had little penetration into the informal seed systems currently in place. Small-scale farmers in these countries continue to plant seed tubers acquired through the informal seed system, i.e. produced on-farm or acquired from neighbors or local markets. Informal seed tubers frequently have poor health status, leading to significant reductions in yield and/or market value (Thomas-Sharma *et al.*, 2015).

The seed rate of potato is very high which increase a total production cost and it is considered as a major problem to use quality seed potato by the growers. Bangladesh Agricultural Development Corporation (BADC) reported that the seed cost of potato is liable to 30 - 40% of total production cost (Anon, 2005). Consequently our total potato productivity is comparatively low. Use of low quality seed is one of the main reasons for low yield of potato in Bangladesh. Moreover, the major constraints to potato production in Bangladesh have been the unavailability of quality and healthy seed potato, difficulties in the production and distribution of disease free seeds, wide range of pests and diseases, insufficient of cold storage facilities resulting in rotting and sprouting of tuber.

Pathogen and pest build-up in potato seed tubers (seed degeneration) is arguably one of the primary causes of low potato productivity in developing countries (Fuglie, 2007; Gildemacher *et al.*, 2009; Cromme *et al.*, 2010). Sometimes, attacks of viruses to potatoes may destroy 80% of the product; therefore, the most effective way to fight viral pathogens is the use of disease-free tubers. Given the progress of tissue culture, conducting studies in this regard seems necessary. (Mahmoudpour, 2014). The commonly proposed solution to this problem has been to increase availability and farmer's access to seed material produced off-farm by specialized seed producers, often government-regulated to certify a minimum health status (Cromme *et al.*, 2010; Frost *et al.*, 2013; Mateus-Rodriguez *et al.* 2013; Kaguongo *et al.*, 2014). However, certified seed has had little penetration into local seed systems in developing countries (Tripp, 1997; Thiele, 1999). It is usually believed that potato seeds produced and preserved by the farmers do not have standard quality. This is the cause of the need for a comprehensive study to ascertain the quality of potato seeds stored by the farmers.

So far in Bangladesh a total of 54 diseases (both biotic and abiotic) of potato have been recorded (Dey and Ali, 1994). Among the diseases, tuber-borne diseases play important role in crop production. Common tuber-borne diseases are soft rot (*Erwinia* spp.), dry rot (*Fusarium* spp.), common scab (*Streptomyces* spp.) Black scurf etc. "Various factors like age of plant, type and time of infection, soil and climatic factors, type of strain of the pathogen and genetic make-up of host plant, influence the disease development in potato crop"(Agrios. 2005).

Moreover, it would be impossible to grow good, healthy potatoes without high quality seed. Most farmers continue to use farm or neighbor-saved seed or seed from informal seed producers. So, the improvement of the health of on-farm seed material is necessary. To narrow the gap between seed supply and demand in most developing countries, the seed production system must be accelerated by different rapid seed multiplication techniques. In addition to the quantity of seed supply, improving the quality and productivity of the seed to be produced is pre-request due to disease and quality issues. These necessities could probably be fulfilled if the seed production scheme undertaken in aseptic conditions of controlled environments particularly the multiplication of pre-basic seeds (Ketema *et al.*, 2016; Hirpa *et al.*, 2012). The pre-basic seed multiplication in our country is very limited. So, it is essential to ensure quality potato seed within farmer's ability through the multiplication of available quality seeds.

Objectives:

The study has been undertaken with the following major objectives:

- ❖ To improve the technique of disease free potato seed production
- ❖ To develop a low-cost seed potato production protocol

CHAPTER 2

REVIEW OF LITERATURE

In this chapter, the previous research works have been reviewed to relating the present study under the following heading.

2.1. Positive selection

A few years ago, a technique known as “positive selection” was suggested by the International Potato Center (CIP) as a possible option for increasing the vigour of smallholder’s seed potato. Positive selection means selecting only the healthy-looking mother plants, showing good production characteristics, for seed collection. Positive selection is well known for both increasing and maintaining seed quality in cross pollinating crops that are reproduced through botanical seed. This technique has resulted in landraces of many crops that are well adapted to the circumstances under which they are selected. In potato farming, however, positive selection will not result in new landraces, as it is vegetative propagated, but it can help in fighting crop degeneration caused by seed borne diseases. (Gildemacher *et al.*, 2007).

Okeyo *et al.*, (2018) carried out a study to assess the effectiveness of Positive Selection (PS) in managing seed borne potato viruses. Sprouted seed potato tubers of nine genotypes; three commercial varieties and six advanced International Potato Center (CIP) clones were screened in the field for two seasons, Field Generation Three (FG3) and Field Generation Four (FG4), respectively. In each season, experimental plots were divided into two sub-plots in which one sub-plot was planted with seed tubers sourced through Random Seed Selection (RSS) and the other with seed tuber sourced through Positive Selection (PS). Positive selection plots had low visual virus incidences, high number of tubers per hill and yield (t/ha) in both FG3 and FG4 growing seasons irrespective of the genotypes. ELISA test also revealed that Potato Virus S (PVS) (78%) was the most predominant virus followed by Potato Virus Y (PVY) (20%), Potato Leaf Roll Virus (PLRV) (16%) and Potato Virus M (PVM) (9%) in RSS plots either with single or multiple infections. Positive Selection plots recorded low virus incidences of PVS (47%), and PVY, PLRV and PVM were absent in the tubers tested with ELISA. This study concludes that Positive Selection is a good management strategy to manage the seed borne potato viruses, and if adopted, small holder farmers can reduce the yield losses arising from use of virus infected seed tubers.

2.2. Seed plot technique

A total of 148 farmer's field trials conducted at 15 districts showed very effective in producing quality seed tuber through seed plot technique (Anonymous. 2012). They found that incidence of virus, bacteria, common scab, and late blight were very low in the trial compared to farmer's practice at neighbor plot. They also observed that in the subsequent two generation from the same seed source following seed plot technique, disease incidence was very low and could be used as seed for 3rd generation without much loss of yield.

2.3. Certified seed

Thomas-Sharma *et al.*, (2015). studied on seed degeneration in potato: the need for an integrated seed health strategy to mitigate the problem in developing countries, and stated that "Seed produced within the formal seed system by specialized growers that has been certified to have pathogen and/or pest incidence or severity below established thresholds. Commonly used synonyms include 'clean seed' and 'disease-free seed'"

2.4. Different planting and haulm pulling time of potato

Proietti *et al.*, (2018) conducted an experiment on the effects of two sowing times and two rates of irrigation and found that quality attributes of early potato can be affected mainly by the cultivar, but the sowing time and the rate of irrigation had limited effect on tuber quality. Thongam *et al.*, (2017) was done an experiment on "Effect of planting dates on growth and yield response of potato Cv. Kufri Pukhraj" at Latur, Maharashtra during September 2012 to March 2013. There was eight planting times such as September 30, October 10, October 20, October 30, November 10, November 20, November 30 and December 10. The earliest planting date of 30th September recorded maximum emergence percentage (at 15 and 20 DAP). Data revealed that the maximum height (52.93 cm and 70.23 cm) at 45 and 75 DAP respectively and maximum number of leaves at both 45 and 75 DAP was recorded in the tuber planted on 10th October while the minimum values were observed on tuber planted on 10th December. Further, the maximum number of tubers (8.20) per plant was recorded in planting date of October 10 which was at par with planting on 30th October and 10th November, while the minimum number of tubers (4.00) per plant was obtained in planting date of 10th December. The highest yield (44.93 kg/plot and 27.74 t/ha) was recorded in planting date of 10th October. The lowest yield (17.45 kg/plot and 10.77 t/ha) was observed in planting date of 10th December. Study conclusively revealed that the potato crop planted on 10th October recorded maximum plant height, number of leaves and yield.

Alam *et al.*, (2017) conducted a field experiment for producing higher processing grade tuber yield and quality by evaluating in relation to different planting times (31 October, 15 and 30 November) and dehaulming dates (80, 90 and 100 days after planting) during 2012-13 potato growing season at Bangladesh Agricultural Research Institute, Gazipur. Results revealed that different growth parameters like plant height, leaves number per hill and foliage coverage were significantly influenced by planting times. Processing and non-processing grade tuber number and yield were significantly affected by all the treatments and their interaction. Significantly higher yield of processing grade tuber were recorded in November 15 planting in combination with all the dehaulming dates, ranged from 20.67 to 21.50 t/ha. Processing quality parameters like specific gravity, dry matter, reducing sugar content were significantly varied by planting times, dehaulming dates and their interaction. Whereas the potato chips colour score were not affected by the planting time and dehaulming but all the processing quality parameters were remained in acceptable range. The highest net return (Tk 1,68,404/ha) with a BCR of 1.93 was obtained in November 15 planting with dehaulming at 90 days after planting.

Jamro *et al.*, (2015) conducted an experiment on planting dates for true potato seed (TPS) nursery, during 2009 and 2010 for comparison of three planting dates i.e. October 15, October 30 and November 15. The results obtained from m^{-2} area showed maximum germination (84.95%), plant height (46.94 cm) average number of micro (1-9 mm) tubers (196.1), small (10-19 mm) tubers (42.15), medium (20-39 mm) tubers (26.56), large (>40 mm) tubers (7.57), weight of micro tubers (1302 gm), small tubers (480.3 gm), medium tubers (340 gm) and large tubers (468.5 gm) were observed when TPS-9804 was planted on 30th October. The overall results for tuber yield showed that TPS-9804 genotype planted on 30th October produced maximum tuber yield (29.46 ton ha^{-1}) as compared to rest of genotypes; hence, TPS-9804 genotype is recommended for raising of TPS nursery with 30th October of planting date.

Mamun *et al.*, (2015) conducted an experiment on the effect of planting time of top-shoot cuttings of potato. Plants produced from top-shoot cuttings planted on 25th November (T_3) produced higher mean tuber yield (32.95ton ha^{-1}) than December planting. Total yield of potato increased 122.8% from early one source crop plants due to taking two times cutting and it was 89.7 % from late one source crop plants. Seed tuber yield increased 167.89% and 95.33% in early and late one source crop plants, respectively. The highest gross net return of Tk. 984,440 was found from whole tuber planted on 10th November with benefit cost ratio of 3.42. From top shoot cuttings, the highest net return of Tk. 739,600 was found in T_3 (25th November planting) with benefit cost ratio of 6.20. The crop grown from early planted top-shoot cuttings also produced higher percentage of A and B grade seed tubers than late planting. The results revealed that top shoot cuttings would be used in potato production for getting maximum economic return.

Bewuketun *et al.*, (2015) was reported that early planting (October 20) delayed emergence and flowering by about 4 and 15 days, respectively and increased plant height by 10.68 cm than the latest planting on November 29. The number of stems per plant increased with delayed plantings however tuber number decreased in late plantings. Early planting produced significantly heavier tuber weight (83.80g) which progressively reduced in subsequent plantings, whereas delay in planting resulted in higher unmarketable yield. Guidene took significantly longer days to emerge and flower (19.2 and 65.6 days, respectively) and plants were significantly taller (77.77cm) than Jalene and local variety.

Bhandari *et al.*, (2015) planting time of potato (*Solanum tuberosum*) varieties was standardized under a block plantation of poplar (*Populus deltoides* Bartr.). Treatments included early, mid and late sown potato varieties viz., Kufri Pukhraj, Kufri Jyoti and Kufri Badshah and five planting times viz., early-November, mid-November, late-November, mid-January and early-February. The best combination of sowing time and variety under block plantation of poplar was late-November sown Kufri Badshah, which produced highest tubers 10 plant⁻¹, maximum yield 426.4 g plant⁻¹ and maximum total tuber yield of 18.33 t ha⁻¹. The tuber yield reduction under poplar plantation compared to open conditions was 6.2% in Kufri Badshah and 11.5% in Kufri Pukhraj when sown during late-November. The mid-January and early-February crops gave lower yield due to poor tuber formation as the tuber growth ceases at temperature above 30°C. The tuber yield (g plant⁻¹) and starch content (mg g⁻¹) of potato crop grown under poplar plantation (113.70 and 55.34) was significantly less compared to crop sown under open conditions (151.50 and 88.45).

Virtanen and Seppanen (2014) conducted an experiment on the haulm killing is used in seed potato production primarily to regulate tuber size. The most common haulm killing method is mechanical-chemical. The timing of haulm killing (when no more than 5% of the crop tubers were over 50 mm in size) and the time between destruction and harvest (21–26 days) were similar to practices followed in seed-potato production. Matilda was the cultivar used. In this study, haulm killing clearly increased plant disease pressure, as black scurf (*Rhizoctonia solani*) could be seen in tubers whose haulm had been destroyed. Black scurf was also observed in mechanical haulm killing. The yield from naturally senesced haulms had less black scurf than the other treatments. In addition, when haulm senescence occurred naturally, crop yield and starch content were highest compared to other treatments.

Sajeda *et al.*, (2013) conducted an experiment on effects of planting time and variety on the yield and processing quality of potato. They found that 15 November showed higher yield.

Rab *et al.*, (2013) developed potato tuberlets from Hybrid TPS, OP-TPS and Tissue culture and evaluated against seed tubers for plant growth, yield and tuber quality. The tuberlets from hybrid TPS had significantly higher percent sprouting (92.767%), plant height (65.783 cm), soil cover (91.250 cm²), number of leaves per hill (35.67) and yield (39.126 ton ha⁻¹) with the minimum disease incidence (0.15%), followed by mini-tubers and OPTPS. The seed tubers had significantly high disease incidence (23.17%) and lower yield (11.414 ton ha⁻¹) but had high tuber quality high TDS (6.242%), dry matter (23.176%) and specific gravity (1.393). Most of the parameters were none significantly affected by sowing on September 15th or September 22nd but plant height, soil cover, leaves per hill and yield declined with delaying sowing to October 8th.

Panigrahi *et al.*, (2013) conducted an experiment on the effect of date of harvesting on yield and related traits following split plot design with 19 genotypes at sub plot and two days of harvesting as main plot. Research finding showed significant interaction effects were present between the genotypes for two days of harvesting. Genotypes like MS/1-4353, K. Pushkar, K. Surya, Chipsona-1, K. Bahar, K. Pukhraj (G7) are very promising yielder. Most of the characters showed significant difference when harvested in late. Except Non-marketable tuber yield all the characters were significant with respect to days of harvesting (A). All the characters were significant with respect to genotypes (B). The interaction effects (A×B) between all the traits were significant for except non marketable tuber yield. In order to exploit the full potentiality of the varieties, varietal selection is an important task.

Bahram *et al.*, (2012) studied the effect of planting and harvesting dates on yield and vegetative growth of two potato cultivars in Ardabil region and observed that cultivars, planting and harvesting dates influenced tuber yield (t/ha), number of tuber per plant significantly.

Singh and Pundhir (2012) stated that rabi season early planted (20th Oct.) potato cultivar Kufri Bahar showed maximum disease severity (95% and 98%) and lowest yield (3.25.55 q/ha and 140 q/ha) followed by medium planted (30th Oct.) and late planted (10th Nov.) crop. In case of Kufri Sutlej, early planted crop showed 20% disease severity in 2005-06 and 70% disease during 2006 - 07 due to more favorable environmental condition. Area under disease progress curve for early planted potato cultivar Kufri Bahar, were 315.0 and 310.5 for both cropping season and it gradually decline with delay in date of planting (207.5 and 174.0 for medium planted and 37.0 and 29.5 for late planted crop for both cropping season).

Sogut *et al.*, (2011) investigated the effect of harvesting time on yield and quality traits for spring season production in different maturing potato (*Solanum tuberosum* L.) cultivars under agro-climatic conditions of southern Turkey in 2006 and 2007. The cultivars tested were Adora (early), Carrera (early), Felsina (mid-early), Marfona (mid-early), Mondial (mid-late) and Vangogh (mid-late). Samples of tubers were harvested at 75, 90, 105 and 120 days after planting (DAP) in spring crop. Early cultivars Carrera and Felsina gave more than 2 ton ha⁻¹ tuber yield at 120 DAP. However, Vangogh and Mondial (mid-late cultivars) proved to be superior cultivars in relation to dry matter, specific gravity or starch content at 105 DAP.

Hassanpanah *et al.*, (2009) reported that the maximum total and marketable tuber yield and marketable tuber number per plant were affected by planting dates.

Vinod *et al.*, (2009) carried out an experiment on the effect of four dates of haulm killing (D1-60, D2-70, D3-80 and D4-90 days after planting) on growth and yield of potato at Dharwad (Karnataka). Haulm killing at 90 DAP recorded the maximum seed size and total tuber yield per plant and per hectare for all seed sizes used. The significant highest seed size and total tuber yield was obtained when haulm killing was done at 90 DAP.

An experiment was carried out by Chang *et al.*, (2005) on the growth patterns of this cultivar including tuber number, size and quality, potato tubers at 60, 70, 80 and 90 days after sowing. The earlier harvests at 70 or 80 days after sowing increased the number of tubers. However, total tuber weight per plant significantly decreased in earlier harvests. Shoot growth was maximum at the early harvesting date 60 or 70 days after sowing. Tuber form 60 days after sowing, the dormant period of early harvest tubers was not different with that of late harvest tubers of 90DAS. These result clearly represented an economic advantage of early harvesting of 70 and 80 DAS because of reducing cost.

Kawakami *et al.*, (2005) reported that delaying planting dates reduced the tuber yield. The yield of potato in general depends on growth rate of tubers and the growth period of potato.

Hipra (2005) conducted an experiment involving potato varieties Al-111 and Al-624 and three harvesting times 70, 90 and 110 days after planting to determine their influence on growth and dry matter production. Highly significant increase in tuber dry matter yield was recorded with increased plant population and delayed harvesting.

Jackson *et al.*, (2005) conducted an experiment on the effect of planting date on the growth and yield of potato (*Solanum tuberosum* L.) plants grown from conventional seed tubers (CT) and microtubers (MT). CT of about 50 g and MT of 1 to 3 g of early (Kitaakari) and late (Norin 1) maturity cultivars were planted at Sapporo, Japan, on May 13, June 4 and June 25, and their growth and yields were investigated. And reported that delaying the date of planting reduced the tuber yield, mainly because of the shortening growing period in MT and CT plants.

Chaubey and Sing (2001) conducted an experiment on the effect of different methods of dehauling on virus incidence in potato seed production and found that among dehauling methods, haulm pulling was found to be the most effective in reducing the virus incidence without affecting the crop yield.

Struik & Wiersema (1999) stated that early haulm killing decreases crop yield but, on the other hand, haulm killing carried out too late increases the risk of pathogens and potato diseases. Haulm killing can be used to advance harvesting, reduce foliage mass, obtain a suitable tuber size, strengthen tuber skins before harvesting and prevent plant pathogens from spreading amongst the foliage and crop.

Kempenaar and Struik (2007) stated that the aim of haulm killing in seed potato production is particularly to control soil-borne or seed-borne diseases, including viruses, black scurf (*Rhizoctonia solani*), late blight (*Phytophthora infestans*), gangrene (*Phoma foveata*), Verticillium wilt (*Verticillium dahliae*) and bacteria.

French (1994) reported that delaying the dates of planting in India reduced wilt incidence. This was attributed to decreasing temperatures. Maximum temperatures during cropping dropped from 31.6-33.2 to 29.3-29.6°C in each of two years by delaying planting for two months. Increased time before planting involves a longer rest period, in which soil suppressiveness may also act.

Chaurassia and Singh (1992) reported that haulms cutting were done at 80, 90, 100, 110 and 120 days after planting and tubers were harvested 10 days after stem cutting and stored for 30, 60 and 90 days. The percentage of tuber weight loss, sprouting and rotting decreased with the delay in haulm cutting.

Kundzicz (1985) observed that harvest date was greatly influenced on the storage loss of potato. The highest losses occurred at late harvesting dates during the storage. At early harvest dates the differences in the amount of damage were remarkable.

Chowdhury and Quasem (1984) stated that haulm pulling of potato during growing season help to avoid transmission of some virus diseases through aphids. They also reported that the actual growing period is also affected by the pulling of haulms during the later growing stage.

Siddique *et al.*, (1984) carried out an experiment on the effects of date of planting under Bangladesh conditions. They reported that the early to mid-November is the optimum time for planting of seed potatoes.

Iritani *et al.*, (1983) conducted an experiment on effect of planting date of potato and found that the differences in germinating temperatures which resulted in increased stem number with later plantings. The germinating soil temperatures were 10, 12 and 15 °C in the 31 March, 20 April and 12 May planting dates respectively. They concluded that economic yields are influenced by stem and tuber number which in turn can be manipulated by planting dates.

Ahmad and Rashid (1980) reported that in Bangladesh the available growing period for potato is short and under the situation, potatoes are to be planted quite early in the season, late planting reduces tuber yield.

Ahmed and Talukdar (1978) reported that late planting reduced the incidence of wilt disease of potato. He advised that late planting could be a good practice to minimize the potato diseases in Bangladesh.

Schippers (1977) found that when potato tubers were harvested in an immature stage, the respiratory activity was very high immediately after harvest, which dropped to a relatively constant level in a period of 3-6 week.

Waterer (2002) was studied the influences of planting and harvest dates on yields and grade-out due to tuber damage by common scab (*Streptomyces* spp.) were evaluated over three cropping seasons using two cultivars of potato (*Solanum tuberosum*) grown on land heavily infested with pathogenic *Streptomyces* species. Early planting and delaying the harvest enhanced yields in both cultivars, but also increased tuber grade-out due to excessive levels of scab. Delaying the harvest reduced marketable yields more than did early planting. The longer harvest was delayed after top-kill, the greater was the grade out due to scab. Increased losses to scab exceeded any increase in tuber yields obtained by delaying harvest. This study demonstrates that common scab of potato may be managed by minimizing the period the crop is in the ground, but that this method of disease management is achieved at the expense of yields. Early planting coupled with timely harvesting after kill-down of the tops appears to be

an effective compromise between the objectives of maximizing yields while avoiding excessive grade-out due to common scab. * Managing the crop in a manner that slows the growth of the scab lesions may represent an additional means for minimizing losses to scab. The optimum temperature for growth of *S. scabies* is relatively high (25–30°C) and losses to scab are more severe in warm regions or growing seasons. Timing planting to reduce the crop's exposure to temperatures suited to growth of the scab lesions may reduce crop losses, providing it does not excessively interfere with productivity of the crop. Time of harvest is already known to influence losses to several other soil-borne potato pathogens.

Sandhu *et al.*, (2012) reported that total and processing grade tuber yield increased significantly as the crop duration was increased from 70 to 90 days. Where the proportion of processing grade tubers yield was increased in 39% and 28% and total yield was increased in 19% and 9% when the crop was dehaulmed at 70 to 80 and 80 to 90 days after planting, respectively.

Dijst (1985) investigates the effect of haulm destruction and additional root cutting on black scurf on potato tubers and suggested that “early haulm killing promotes development of sclerotia. Advancing the killing of vines does not lead to a rapid disintegration of the roots. The initially fully functional root system continues to function as water pump for about a week”. As evaporation through the foliage ceases, tubers serve as a sink for the water surplus, consequently increasing in mass and commencing leakage.

Lootsma and Scholte (1996) were conducted a two year field experiment was twice to assess effects of chemical soil disinfection at planting and methods of harvesting potatoes on stem infection with *Rhizoctonia solani* in the subsequent year. In the first year of the experiments seven methods, including one with soil disinfection at planting, were applied in August. In the following year, *R. solani* stem and stolon infection (disease severity) on potato plants were assessed in June. Soil treatment at planting with pencycuron resulted in lowest disease severity in the following year. Compared with chemical haulm killing and haulm pulling, immature-crop-harvesting also resulted in a lower disease severity, but only when black scurf was scarce on tubers at harvest in the preceding year.

Kumar, *et al.*, (2017) studied on A Comprehensive Overview on of Potato and stated that “Black Scurf on the tubers develop late in the growing season. *Rhizoctonia solani* is a soil borne pathogen. It is managed by the integrated approaches such as cultural control *viz*; disease free tubers, crop rotation, organic amendments, soil moisture and management, harvesting time, biological and chemical control”.

2.5. Size of seed potato

Khalafalla (2001) reported that yield of potato decreased with decrease in seed size and increase in spacing. Seed size had significant effect on marketable tubers per plant, marketable tuber weight, and stems plant⁻¹.

Shingrup *et al.*, (2003) investigated the effect of row spacing (45 and 60 cm) and tuber size (6-25 g and 26-45 g) on growth, yield and yield components of potato cv. Kufri Jyoti and reported that plant growth and development increased with increased tuber size. The tuber size of 26-45 g recorded significantly higher yield but average weight of tuber was higher in 6-25 g tuber size.

Upadhy and Cabello (2001) studied the influence of seed size and density on the performance of direct seedling transplants from hybrid true potato seed and reported that seed size and density strongly suggest a high correlation between seed size and yield.

BongKyoon *et al.*, (2001) determine the effects of mini-tuber size on plug seedling growth and field performance of plug seedlings. For a control, common potato tubers weighing 50 g were also planted. The authors reported that as size of seed tubers planted increased from 10 to 50 g, seedling height decreased from 24.6 to 20.0 cm while shoot number per seedling increased from 2.0 to 3.5, main stem diameter from 4.3 to 6.1 mm, and fresh weight of root + top from 9.3 to 19.4 g/seedling. Plug seedlings raised from 50 g tubers was produced 22% more tubers per plant and had 21% higher >80 g tuber yield than the directly planted potatoes.

Verma *et al.*, (2007) reported that the seed tuberlet size of 30-40 g resulted in significantly superior tuber yield, which was at par with the tuber yield obtained from 10-20 g seed.

Mayakaduwa *et al.*, (2017) showed that the size of the seed tubers influenced emergence and number of stems/liner/m. There was significantly higher emergence and stem number/m recorded in whole tubers of 60 g, 120 g and tuber pieces of 60 g whereas the lowest was recorded with 15 g tuber pieces. Similarly, higher canopy height and diameter was recorded from whole tubers of 60 g, 120 g and tuber pieces of 60g during both *Yala* seasons tested. The highest marketable yield of potato of size >28 mm also was recorded from whole tubers of 60 g, 120 g and tuber pieces of 60 g in both seasons. It was found that the emergence, growth and yield decreased with decreasing size of seed tuber planted. Thus, it could be concluded that optimum size of seed tubers is either cut piece or whole tubers of 60 g.

Michael *et al.*, (2012) stated that seed sizes had significant differences in mean percentage germination at 9, 10, 11 and 12 days after planting across the four seed sizes. Plants from larger seed potato tubers exhibited greater physiological growth and yield (kg/ha) compared to smaller seed tubers when the experiment was terminated at 95 days after emergence. Large and very large seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites as measured by growth components and yield at all plant density levels compared to small and medium sized seed tubers. This had implications on the duration of the bulking, physiological growth and consequently on yields obtained at harvest. The large size seed tubers, with their relatively larger food reserves, produced large plants which established faster and produced vigorous stems, which increases the efficiency of biomass partitioning to the tubers. At the same time, plant population density had no significant ($p>0.05$) effect on the number of days to emergence. From the results obtained in this study, it can be concluded that the optimum plant population density for good yield was 90 by 30 cm and that large and very large seeds gave the best yield.

Gulluoglu and Aroglu (2009) reported that planting larger seeds positively affected all growth and yield components. Tuber yield per hectare was increased up to certain stem density and then was started to decline at all seed sizes. The optimum stem density increased with increasing seed size. The using larger tubers had an advantage for vigorous early growth and for obtain high tuber yield in early potato production in the mediterranean-type environments. Seed size should be considered during recommendation for planting density in potato production.

Sarker and Kabir (1989) obtained markedly maximum crop coverage with increase in the size of seedling tuber. Large seedling tubers gave maximum crop coverage at maximum vegetative growth stage.

Sultana *et al.*, (2001) reported that seedling tuber size significantly influenced the growth (time to emergence, plant height, stem number per hill and leaf area coverage) and yield of potato. Yield was increased with increasing seedling tuber size.

Patel *et al.*, (2008) observed that better growth and yield could be achieved by planting 51-70 g seed tubers with a physiological age of 375 degree days.

2.6. Gibberellic acid treated seed potato

Awati *et al.*, (2016) stated that in case of plant growth enhancers, plants stems were thinner and with plant growth retardants, stem girth was thicker as compared to controls. This may be explained by the high levels of GA accumulation in plants treated with growth enhancers which, resulted in higher cell division and increase in plant height with thin stem.

Hassani *et al.*, (2014) reported that use of gibberellic acid reduced the sprouting time from 25 to 13 days. Increasing the mini-tuber size, the days to dormancy breaking decreased. The difference in seed size causes a difference in number of the sprout. The number of sprout increased whatever as well as seed tuber size increased. Therefore application of GA₃ is advisable for decreasing days to sprouting, accelerating sprout length and consequently resulted in breaking mini-tuber dormancy of potato for short time.

Prasad *et al.*, (2013) found that there was a linear increase in growth parameters like plant height and number of branches per plant with increasing level of GA₃ (20, 40, 60 and 80 ppm) and NAA (25, 50, 75 and 100 ppm).

Alexopoulos, A. A., Akoumianakis, K. A. and Passam, H. C. (2006) stated that application of GA₃ 30 DAT significantly increased plant height and the number of tuber, but not the weight of tubers formed per plant. The total leaf area was increased by early (30 DAT) application of GA₃ in both the spring and autumn crops. Since leaf number was unaffected by the PGR treatments, the increase in total leaf area resulted from an increase in average leaf size. Plants that had been treated with GA₃ early in the growth cycle consistently produced more elongated tubers (37.3% of total tubers in the autumn crop and 31.6% in the spring crop) than the control or other PGR treatments. When GA₃ was applied at 60 DAT, plant height was increased, but tuber number, weight and dry matter content were not affected. Late application of GA₃ induced a high percentage of sprouted tubers prior to harvest and significantly increased the physiological age of the tubers, as reflected by an increased rate of respiration, sprouting and weight loss after harvest. Although early application of GA₃ also increased tuber sprouting prior to harvest, it had no effect on sprouting, respiration and weight loss after harvest. Application of GA₃ early in the vegetative cycle may be useful for the production of mini-tubers for propagation, whereas application at a later stage may aid in early planting by accelerating the breaking of tuber dormancy.

Javanmardi and Rasuli (2017) studied of gibberellic acid (GA_3 at 0, 100, 200 and 400 $mg \cdot L^{-1}$ levels) and zinc sulfate (at 0, 500, 1000 and 2000 $mg \cdot L^{-1}$ levels) were foliar sprayed on potato plants of 20 and 50 days after tuber sprouting, respectively. There was no significant difference in all measured criteria between the two years of experiment. Compared to control, a 38% increase in total tuber yield resulted from treatment with 200 $mg \cdot L^{-1}$ GA_3 and 1000 $mg \cdot L^{-1}$ zinc sulfate.

Akbari *et al.*, (2013) stated that the production of seed tubers increased by using gibberellic acid hormone at concentration of 5 and 10 mg/lit respectively. Also, higher total weight of seed tubers produced from application of 5 and 10 mg/lit GA_3 , which statistically had difference from application of 0 mg/lit GA_3 ($p \leq 0.05$).

Loretta and Mikitzel (1993) were stated that GAs treatments increased stem and tuber numbers per hill and produced of more seed-sized (up to 226 g) tubers and fewer large (greater than 340 g) tubers.

Daniel O. Caldiz. (1996) stated that the use of PGRs under both field and glasshouse conditions in cvs. Mailen and Spunta can result in increased tuber number in the seed fraction.

Virtanen *et al.*, (2013) reported that gibberellic acid (GA) treatments significantly increased the number of sprouts and at lower concentration (100 mM) of GA increased the number of tubers in the cultivar Fambo of potato.

Barani *et. al.*, (2013) showed that application of gibberellic acid at low concentrations (5 and 10 mg/lit) was able to increase general performance and productivity of seed tubers of potatoes. Seed tuber production was increased by application of gibberellic acid in all cultivars. Total weight of seed tubers produced by application of 5 mg/lit GA_3 was statistically different compared to control. Also, stated that after one week from application of GA_3 , starch content decreased and total content of sugar increased in potato tuber. The tubers treated with GA_3 sprouted earlier while in control sprouting was very late and slow.

Asalfew, G. K. (2016) stated that both pre and post-harvest treatments of GA_3 , have effect on breaking dormancy, early emergence of shoots, increased tuber yield and quality of potato. Haulm applications of GA_3 at 750 and 1000 ppm reduced dormancy period by 24 days and 27 days, respectively. It also hastened early physiological maturity, increased average sprout number and sprout length of tubers.

Myhre and Eddins. (1957) stated that most of the tubers borne by the gibberellic Acid treated (25, 50 and 100 ppm) plants produced elongated and pear shaped potato tubers.

El-hamady. M. M. 2017. Stated that gibberellic acid is a naturally occurring plant growth regulator which may cause a variety of effects, including the stimulation of seed germination by breaking seed dormancy. Gibberellins influence the dormancy of seeds, shoots, and other plant parts. The increasing rates of concentration of GA₃ from 0 ppm GA₃ to 30 ppm GA₃ markedly increased plant height, chlorophyll content, foliage fresh and dry weight g/plant and No. of tubers/plant, tuber weight g/plant, tuber yield t/ha, TSS%, crude protein, tuber dry matter and starch %. It could be stated that increasing of GA₃ rates from 0 ppm GA₃ to 30 ppm GA₃ significantly increased plant height, chlorophyll content, foliage fresh and dry weight g/plant and No. of tubers/plant, tuber weight g/plant, tuber yield t/ha, TSS%, crude protein, tuber dry matter and starch % by 8.82, 9.35, 4.5, 4.58, 34.7, 12.23, 12.48, 11.96, 25.15, 13.69 and 19.04 %, respectively as an average of both seasons. He concluded that soaking seed tuber in 30 ppm GA₃ and adding 172.5 kgK₂O/ha maximized tuber yield and its quality.

2.7. Degeneration of potato

Degeneration is a common phenomenon of potato with the progress of cultivation year.

Sarker *et al.*, (2018) stated that the percent infection of PVY was ranged from 10.8-16.7 %, 19.2- 37.5% and 39.2-61.7% in 1st, 2nd and 3rd generations, respectively depending on the varieties (Asteri x, Cardinal, Diamant and Granula). Whereas, PLRV infection varied from 5.0-10.0%, 27.5-30.8% and 37.5-52.5% in 1st, 2nd and 3rd generations, respectively depending on the varieties. Asterix and Diamant are more tolerant than that of Cardinal and Granule. 1st generation was produced maximum number of tubers per hill, yield per hill and seed yield per plot compared to 2nd and 3rd generations all the four potato varieties. Diamant showed less degeneration effect on number than the other varieties. Asterix and Diamant performed better than that of Cardinal and Granule in all the cases. PVY causes more severe reduction of yield per hill than that of PLRV.

Ghimire *et al.*, (2016) stated that there is serious loss (27–46%) on an average in the subsequent year in the productivity of potato. To decrease the rate of degeneration insect proof net can be

used which is cheaper and environment friendly resulting the satisfactory yield in the subsequent generation.

Singh *et al.*, (2014) advised to maintain their seed stocks of cvs. K. Badshah, K. Pushkar and K. Surya up to three consecutive years adopting seed plot technique for maintaining assured quality seed and yield potential which also gives assurance against introduction of other tuber borne diseases like common scab, black scurf, brown rot etc.

Islam *et al.*, (2014) stated that the height was reduced significantly due to infection of PVY as compared to healthy plants. The height reduction due to PVY infection was recorded as the highest (29.09%) in Felsina while the lowest (2.95%) reduction was observed in Febula. The reduction percentage of the number of stem varied from 2.61 to 32.62% due to PVY. The highest (32.62%) reduction of number of stem per plant was recorded in Felsina, whereas the lowest (2.61%) reduction was found in Diamant in case of PVY infection. In respect of number of tubers per plant, the reduction percentage of number of tuber per plant varied from Fontane (10.07%) to Febula (31.96%). The yield reduction was recorded as the highest (54.91%) in Diamant due to PVY infection.

Ali *et al.*, (2013) stated that the first year harvest was carried forward along with the good quality seed to compare the yield loss in subsequent years. Incidence of Mild Mosaic, Severe Mosaic and Potato Leaf Roll was higher in ware crop as compared to quality seeds. The results revealed that seed stocks of cv. Kufri Jyoti can be maintained for more than 4 years and cv. Kufri Giriraj can be maintained for 3-4 years in both the states following the essentials of “Seed Plot Technique”.

Rab *et al.*, (2013) stated that the tuberlets from hybrid TPS had significantly higher percent germination (92.767%), plant height (65.783 cm), soil cover (91.250 cm²), number of leaves per hill (35.67) and yield (39.126 ton ha⁻¹) with the minimum disease incidence (0.15%), followed by mini-tubers and OPTPS. The seed tubers had significantly high disease incidence (23.17%) and lower yield (11.414 ton ha⁻¹) but had high tuber quality high TDS (6.242%), dry matter (23.176%) and specific gravity (1.393).

Rahman and Akanda (2010) reported that presence of PLRV infected tubers at 20% and higher rate caused significant increase in disease incidence and reduction in plant height, stem number, tuber number, and tuber yield as compared to that in control. Incidence of PLRV in the experimental fields, reduction in plant height, stem number, tuber number, and tuber weight per hill was positively and linearly correlated with levels of their inoculum. Spraying of Nimbecidine against insect vector did not show significant influence on plant growth and tuber yield.

Rahman and Akanda (2009) stated that the least incidence of PVY and PLRV was recorded when seed tubers from sprout cutting were used. Whereas, the highest incidence of the viruses was observed where conventional seed tubers were planted. Incidence of PVY, PLRV and their mixed infection was lower in earlier generations as compared to later generations.

Nolte *et al.*, (2004) stated that 1% increase in incidence of seed borne PVY resulted in a tuber yield reduction of 0.17–0.18 t ha⁻¹.

Ranalli *et al.*, (1994) reported that final ground cover was almost complete only in the plots derived from normal tubers and decreased with the size of the mother tubers. Normal seed, minitubers and microtubers yielded respectively 50.8, 31.7 and 17.0 t/ha and number of tubers per m² was also affected. Mother tuber type also affected the yield distribution in three grades (<36, 36-55, and 55-80mm) and micro and minitubers produced many small tubers.

Hussain *et al.*, (1978) reported that the yield of spring planted potato cv. Desire was reduced by 20% and of cv. Patrones by 70.5% when seed tubers had been imported three years ago and propagated annually in Pakistan compared with freshly imported tubers.

Tien *et al.*, (1982) described that in most parts of China successive potato crops from the same stock found to be degenerated rapidly probably due to virus infection and high temperature.

Healthy seed stock of 7 potato genotypes was planted at Rajgurunagar to identify the most suitable variety to cultivate in the Plateau region of Maharashtra, India, where insect vectors of viruses and mycoplasma-like organisms affecting potatoes have been reported. Tubers produced from this crop were also grown. Disease was most prevalent amongst the second crop, and a significant correlation was found between yield reduction and incidence of

degenerative diseases (Bhandal and Naik 1991). Brandolini *et al.*, (1992) reported that degeneration of seed tubers caused by viruses like PVY and PLRV is a major constraint to potato cultivation in many warm tropical areas. Sawicka (1994) reported that in course of five years potato multiplication period there was a linear decrease of tuber yield and increase of infection by viruses. The infection of PVY and PLRV was found to be parabolic. The highest tubers yield decrease was observed in the varieties Atol, Benyl, Narew and San.

During 1988-89 and 1993-94 the rate of degeneration of prevalent potato varieties was studied by Khurana *et al.*, (1998) in the major potato belts of India. No significant reduction in yields was recorded and a low incidence of viruses suggested that the seed stocks of cultivars Kurfi Chandramukhi, Kufri Bahar and Kufri Badshah can be maintained for >5 years following the Seed Plot Technique in NW and Central Indo-Gangetic plains. In North Gujarat, cultivars Kufri Badshah and Kufri Bahar can be maintained for 4 years and Kufri Chandramukhi for 3 years. Similarly cultivars Kufri Jyoti and Kufri Badshah remained healthy for 4 years in the eastern Indo-Gangetic plains. The degeneration of seed was correlated with initial appearance, population build-up and vectorial activity of the main aphid vector, *M. persicae*. Potato stocks showed faster degeneration in the Satpura region where aphids remained above the critical level throughout the crop season (October to January) compared with NW and Central Indian plains where aphids do not cross the critical level before the end of December.

Disease-free seed potatoes of six recommended cultivars were imported into Bangladesh from India and studies conducted to ascertain the number of consecutive generations after importation that seed potato can be used as potential seeds without appreciable yield loss and increased virus incidence. The four succeeding crop generations were evaluated for crop yield, and PVY and PLRV incidence. The plants were regularly sprayed with fungicides and insecticides to protect against diseases and insects. PLRV infection was the highest in the fourth generation and lowest in the first. PVY incidence was not observed in the first generation for all the cultivars; it was first observed in the second generation and its incidence increased with each succeeding generation. The incidence of both viruses was lower in Cardinal and Elvira compared to the other cultivars. PVY incidence was the highest in Multa. All cultivars produced the highest yields in the second generation, with yields gradually decreasing in subsequent generations. Cardinal gave the highest yield among the cultivars followed by Elvira (Bari *et al.*, 1998).

CHAPTER 3

MATERIALS AND METHODS

To fulfill the research objectives, the experiments were conducted at the research field of Plant Pathology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur during October 2014 to March 2018. The details of the Materials and Methods are outlined below:

Experiment 1. **Seed quality assessment of farmer's produced seed potato of variety cardinal**

3.1.1. Experimental site

The experiment was conducted to find out suitable method for improving the farm saved potato seed production by the producer with increase productivity at the research field and post graduate laboratory of Plant Pathology Division, HSTU, Dinajpur, during November 2015 to March 2016. The experimental site was high land and the soil was sandy loam in texture under AEZ 1 (Old Himalayan Piedmont plain). The pH value of the soil was within the range of 5.7 to 6.0. The Randomized complete block design (RCBD) with 03 (three) replications were used in these experiments. The unit plot size of the experiment was 2.4 m × 3.5 m. The most popular variety "Cardinal" was used in these experiments.

3.1.2. Treatments

Treatments were as follows

1. Farmer's farm saved seed,
2. Seeds of Positive selection,
3. Certified seed
4. Seeds of seed plot technique and
5. Truthfully labelled seed (local seed company)

3.1.3. Seed collection

Farm saved seeds was collected from farmer's house. Seeds of positive selection was collected directly from the farmer's fields by selecting healthy and vigorous plants at the 65 days after planting. Certified seeds was collected from BADC, Thakorgong. Seeds of seed plot technique was collected from the farmer's seed plot which was cultivated separately from the general cultivation to produce next year seeds with help of on farm research division (OFRD), Agricultural Research Centre (ARC), Rajbari, Dinajpur. The truthful level seeds was collected from local seed producing company (M N Agro & Traders) from Thakorgong. The collected seed potatoes were stored in local cold storage.

3.1.4. Land preparation

The tillage operations were done for 4-5 times during 25 Oct to 03 November 2015. The experimental field was opened with power tiller. Then it was thoroughly prepared by ploughing and course ploughing by laddering. The soil was prepared to a good tilth. The weeds and stubbles were removed from the field. Finally the soil was leveled with a harrow (laddering) by a power tiller.

3.1.5. Fertilizer application

The recommended doses of fertilizers and manure, as the fertilizer recommendation guide of Bangladesh Agricultural Research Council (BARC 2005) were applied. Cow dung was incorporated in the soil during last land preparation at the rate of 15 ton per hectare. Urea, Triple Super Phosphate (TSP), Muriate of Potash (MoP), Gypsum, Zinc Sulphate and Borax were applied at the rate of 320, 150, 209, 120, 08 and 10 kg per hectare, respectively. The entire amount of TSP, MoP, gypsum, zinc sulphate and borax were applied at the time of final land preparation. Urea was applied in two equal installments, the first installment during final land preparation and the 2nd installment at the 35 days after planting.

3.1.6. Preparation of planting materials

The seed tubers of the potato variety “Cardinal” was taken out from the cold storage 10 days before planting and was spread over the floor under diffused light for sprouting. The good looking, healthy and well sprouted tubers was used for planting.

3.1.7. Planting of seed tubers

The well sprouted seed tubers were placed at the depth of 5-7 cm apart in the tine. Hill to hill distance was 25 cm and row to row distance was 60 cm were maintained properly. After planting the seed tubers was covered with soil.

3.1.8. Intercultural Operations

The crop was raised as per standard agronomic practices during main season

3.1.8. 1. Weeding and mulching

Weeding was done manually as and when necessary to keep the plots free from the weeds. The soil was mulched by breaking the crust for an easy aeration and to conserve soil moisture after each irrigation.

3.1.8.2. Earthing up

Earthing up was done two times during growing period. The first earthing up was done after planting and second earthing up was done at 35 days after planting which was processed by top dressing the remaining dose of urea.

3.1.8.3. Irrigation

Irrigation was provided thrice throughout the growing period. The first irrigation was applied at the 10 days after planting followed by another two irrigations were given at 35 days 50 days after planting.

3.1.8.4. Plant protection

Proper control measures were taken to control insect pest (cut worm and aphid). Dursban @ 5 ml per litre and Metasystox @ 1 ml per litre was applied respectively, to control cut worm and aphid. The fungicide Mancozeb 60% @ 2.0 gm per liter was sprayed at every 10 days interval as routine spray for seed potato production to keep the potato plants free from late blight infection. After taking aforementioned protection, in case of the symptoms of late blight diseases was observed, Acrobat MZ (Mancozeb 60% + Dimethomorph 9%) @ 2.0 mg per litre and Melodi duo 66.8WP (Propineb 61.3% + Iprovelicarb 5.5%) @ 2.0 mg per litre were used for two times at 3 days interval to control the late blight.

3.1.8.5. Harvesting

The crop was haulm pulled at 75 DAP. After 10 days haulm pulling the crop was harvested. The ten plants were harvested at the first time from each plot and then the rest of the plants was harvested with help of a country plough and spade. Care was taken to avoid injury in potatoes during harvesting.

3.1.9. Data collection

Data was recorded on these following parameters:

3.1.9.1. Percentage emergence

Seed potato emergence percentage or plants per plot was recorded by eye observation at 20 DAP and 30 DAP.

3.1.9.2. Plant height (cm)

Plant height (cm) was recorded at 30, 45, 60 DAP and haulm pulling time by using meter scale. It was measured from the soil surface to the tip of the leaves of the tallest stem when pulled erectly. Plant height was recorded from five representative plants in each plot.

3.1.9.3. Percent disease incidence of plant

The percent disease incidence of different field diseases was recorded by observing the symptoms of diseases like Potato virus Y (PVY) (Plate 1 A, 1 B, 1 C), Potato leaf roll virus (PLRV) (Plate 2 A and 2 B), Potato mosaic virus (PMV) (Plate 3), *Rhizoctonia* canker (Plate

4) and Bacterial wilt (Plate 5), etc. Before haulm pulling virus infected plants were identified observing the symptoms expressed by the plants. Seed collected from the virus infected plants were kept separately for ELISA test. DAP-ELISA test was done following the fundamental protocol outlined by Clark and Adams (1977) and modified by Akanda *et al.*, (1991) in the laboratory of Tuber Crop Research Centre (TCRC), BARI, Gazipur. The wells of microtiter plate were examined by eyes. Wells in which yellow colour develops indicated positive results. Wells which remained colourless indicated negative results. The validity of colour development was confirmed comparing with the results of the positive and negative control.

Assessment of incidence of diseases

The incidence of PLRV, PVY and PMV and bacterial wilt was assessed with the following formula-

$$\text{Percent disease incidence of plants} = \frac{\text{Number of plants infected by disease}}{\text{Total number of plants observed}} \times 100$$



Plate 1 A. Potato virus Y infected plant



Plate 1 B. Severely infected plant with Potato virus Y



Plate 1 C. PVY infected plant with tuber



Plate 2 A. Potato leaf roll virus infected plant



Plate 2 B. PLRV infected plant with tuber



Plate 3. Potato mosaic virus infected plant



Plate 4. Black scurf of potato infected plant



Plate 5. Bacterial wilt of potato infected plant



Plate 6. Common scab infected tuber



Plate 7 A. *Rhizoctonia* Canker infected tuber



Plate 7 B. *Rhizoctonia* Canker infected tuber

3.1.9.4. Tuber number per plant

Number of tubers per plant was recorded after harvest from randomly selected five plant and calculated.

3.1.9.5. Yield

After harvest, tuber weight per plot was taken and the yield was calculated. Data of tuber yields per plant was counted from five plants of the central two rows of each experimental plot. Total yield was obtained from the whole plot after harvest. Tubers were graded into four categories

namely over size (> 55 mm), “B” grade (40-55 mm), “A” grade (28-40 mm) and small size (10-28 mm) by using square frame of respective sizes (Huda, 2010) as practiced in Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Gazipur. Total tuber number, total tuber weight, total seed tuber per plant, total seed tuber weight per plant were determined. Moreover, the tuber weight and number of each category was recorded.

3.1.9.6. Number of infected tuber

The number of infected tubers and healthy tubers was counted by eye inspection of the tubers at room storage condition. The diseases are mainly Common scab (**Plate 6**), *Rhizoctonia* canker (Plate 7 A and Plate 7 B) and Deformed tuber. Percentage of infected tuber (*Rhizoctonia* canker, Common scab, deformed) were calculated using the following formula (Ikbal *et al.*, 2019):

$$\text{Infected tuber (\%)} = \frac{\text{Number of infected tuber}}{\text{Total number of tuber}} \times 100$$

3.1.9.7. Statistical analysis

Data were subjected to statistical analysis to find out the levels of significance of the experimental results. The mean of all the treatments were calculated and analysis of variance was performed and the mean differences were adjudged by Duncan’s Multiple Range Test (DMRT) at 5% level of probability using the statistical computer package program, MSTAT-C (Russell, 1986).

Experiment 2. **Effect of different planting and haulm pulling time on quality and health of seed potato**

The experiment was conducted to find out the appropriate planting and haulm pulling time for disease free seed potato production and to escape the potato field diseases for seed potato production at the research field and post graduate laboratory of Plant Pathology Department, HSTU, Dinajpur, during October 2016 to March 2017 (Plate 8).

The experimental site, design, replication, plot size, spacing and variety were done as described in the previous experiment number 1.

3.2.1. Treatments

The experimental treatment was arranged as two factors factorial experiments where the treatments arrangement were as follows-

Factor A: Different planting time

1. Planting at 15th October 2016
2. Planting at 4th November 2016
3. Planting at 24th November 2016
4. Planting at 14th December 2016

Factor B: Haulm pulling (HP) at different time of days after planting (DAP)

1. Haulm pulling (HP) at 68 DAP
2. Haulm pulling (HP) at 75 DAP
3. Haulm pulling (HP) at 82 DAP
4. Haulm pulling (HP) at 89 DAP



Plate 8. The experimental plots of different planting and haulm pulling time of potato

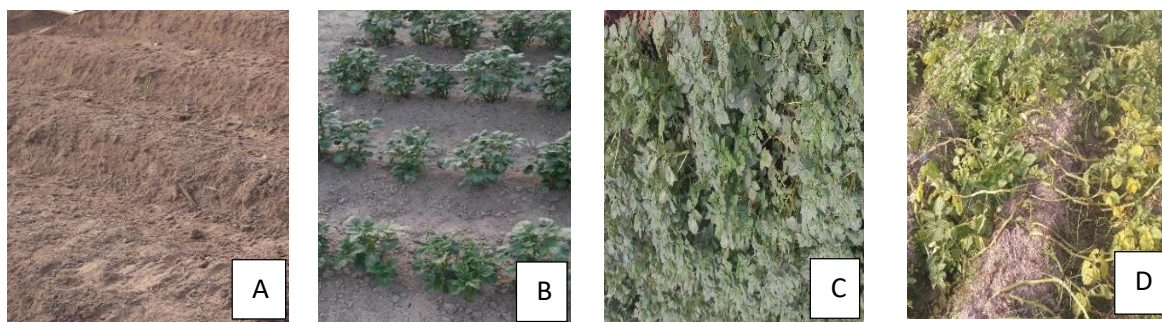


Plate 9. Different stages of potato in the experimental field; A. Potato planted field, B. Seedling stage of potato, C. Vegetative stage of potato D. Maturity stage of potato

3.2.2. Isolation distance

Isolation distance was maintained properly. The research plot was 15 m away from *Solanaceae* crop and 30 m from other potato fields.

3.2.3. Land preparation

The land preparation, fertilizer application was done as described in the previous experiment number 1. After land preparation the collected and sprouted seeds were planted at different time such as i) 15th October 2016, ii) 4th November 2016, iii) 24th November 2016, and iv) 14th December 2016.

3.2.4. Preparation and planting of planting materials, intercultural operations

Preparation of planting materials and planting seed tuber, intercultural operations and statistical analysis were done as described in experiment number 1. Planting was done on 15 October, 4 November, 24 November and 14 December 2016, the well sprouted seed tubers were placed at the depth of 5-7 cm apart with the tine.

3.2.5. Harvesting

The crop was haulm pulled at different time such as 68 DAP (Days after sowing) 75 DAP (Days after sowing), 82 DAP (Days after sowing), and 89 DAP (Days after sowing). After 10 days haulm pulling the crop was harvested. The ten plants were harvested at the first time from each plot and then the rest of the plants was harvested with help of a country plough and spade. Care was taken to avoid injury in potatoes during harvesting.

3.2.6. Data collection

Data was recorded on these following parameters:

3.2.6.1. Percentage germination and plant height (cm)

Percentage germination and Plant height (cm) were recorded as described in experiment number 1.

3.2.6.2. Number of stem per hill

The Number of stem per hill was recorded from the randomly selected five plants from each plot at 30 DAP, 45, 60 DAP and haulm pulling time (Plate 9.A, 9.B, 9.C and 9.D).

3.2.6.3. Leaf area coverage (%)

The leaf area coverage was estimated using the quadrant method outlined by Burstall and Harris (1983). A wooden frame of 100 x 100 cm divided with wires into 100 rectangles was used. The frame was held over the crops at four designated sites per plot. It was estimated by looking vertically down onto the grid and counting the number of rectangles more than 50% filled with green leaf (plate 10). The value of the total number of rectangles gave the percent leaf area coverage. The canopy cover measured at 30, 45, 60 DAP and haulm pulling time (Plate 9. A, B, C).



Plate 10: pictorial view of collecting data of leaf area coverage

3.2.6.4. Canopy weight per plant

After haulm pulling the all pulled up plants from each plot were weighted and calculated the average canopy weight per plant.

3.2.6.5. Percent disease incidence of plant

The percent disease incidence of different diseases PVY, PMV, PLRV and bacterial wilt were recorded as described in experiment number 1. In addition, the following data were also recorded-

Assessment percent and incidence of late blight of potato

Late blight (LB) of potato was observed at 1st week of January 2017 due to presence of low temperature and foggy weather. Primary data were taken just before 1st spray of fungicides (Acrobat MZ 72 @ 2.0 g / lit. and Melodi duo 66.8 WP @ 2.0 g / lit), the 2nd time and 3rd time data were taken at 7 days after infection and 14 days after infection, respectively. Data were taken on foliage infection according to disease severity 1-9 scale (James *et al.*, 1971, Rahman *et al.*, 2008) was as Table 1.

Table 1. Disease severity 1-9 scale of late blight of potato (Rahman *et al.*, 2008)

Score	% foliage affected	Description
1	0	No disease observed
2	0.1	0.1% blighted (a few scattered plants are blighted: no more than 1 or spots in 10 meter radius)
3	1	1% blighted (upto to spots per plant or general light infection)
4	5	5% blighted (about 50 spots per plant: upto 1 in 10 leaflet infected). More than 5% but less than 25%.
5	25	25% blighted (nearly every plant affected, but plants looking normal form) More than 25% but less than 50%.
6	50	50% blighted (every plant affected and about 50% of the leaf area is destroyed) More than 50% but less than 75%.
7	75	75% blighted (every plant affected and about 75% of the leaf area is destroyed) More than 75% but less than 90%.
8	95	95% blighted (only few leaves on the plant, but stems are green). Only very few green areas leaf (much less 10%)
9	100	100% blighted (all leaves dead, stems dead or drying. Foliage completely destroyed).

PDI (Rahman *et al.*, 2008) was estimated as follows by selecting 16 plants randomly from each plot:

$$\text{PDI} = \frac{\text{Class frequency}}{\text{Number of plants assessed} \times \text{Highest score of scale}} \times 100$$

Assessment of percent heat injury

The incidence of heat injury was assessed with the following formula-

$$\text{Percent disease incidence of plant} = \frac{\text{Number of infected plants}}{\text{Total number of plants observed}} \times 100$$

3.2.6.6. Tuber number per plant, yield, number of infected tuber and deformed tuber

Tuber number per plant, yield, number of infected tuber and deformed tubers were recorded as described the Experiment number 1.

3.2.6.7. Disease index and incidence of Common scab

The presence of disease symptoms was checked out from the harvested tubers of each treatments (potatoes of five randomly selected plants) and disease rating was recorded if there was presence of disease symptoms. The treatments were categorized in different disease reactions according to the disease scale described earlier (Patel, 1991) as given in (Table-2).

Table-2: Disease rating scale for common scab of potato suggested by Manthan *et al.* 2016

Rating	Description of symptoms
0.0	Healthy tubers
1.0	1-10 percent tuber surface was affected
2.0	11-25 percent tuber surface was affected
3.0	26-50 percent tuber surface was affected
4.0	Above 50 percent tuber surface was affected

The disease index and disease incidence (%) was calculated according to the equations given below

$$\text{Disease index} = \frac{\text{Total number of infected tubers} \times \text{Disease rating}}{\text{Total number of tubers}}$$

$$\% \text{ Disease incidence} = \frac{\text{Total number of infected tubers}}{\text{Total number of tubers}} \times 100$$

3.2.6.8. Disease index and incidence of *Rhizoctonia* canker of potato

The presence of disease symptoms was checked out by looking symptoms from the harvested tubers of each treatments (potatoes of five randomly selected plants) and disease rating was recorded if there was presence of disease symptoms. The treatments were categorized in different disease reactions according to the disease scale described earlier (Kulkarni and Chavhan, 2017) as given in below. The disease index and disease incidence (%) was calculated according to the equations given below

$$\text{Disease index of } Rhizoctonia \text{ canker} = \frac{\text{Total no. of infected tubers} \times \text{Disease rating}}{\text{Total number of tubers}}$$

$$\% \text{ Disease index of } Rhizoctonia \text{ canker} = \frac{\text{Total no. of infected tubers}}{\text{Total number of tubers}} \times 100$$

Disease rating scale of *Rhizoctonia* canker of potato:

Observation was done by using 0 - 4 scale and Percent Disease Incidence was calculated (Kulkarni and Chavhan, 2017).

- 0 - Healthy
- 1 – Up to 25% tuber area affected
- 2 – 26-50% tuber area affected
- 3 – 51-75% tuber area affected
- 4 – More than 75% tuber area affected

3.2.6.9. Statistical analysis

Statistical analysis were done as described the Experiment number 1.

Experiment 3. **Effect of tuber size and gibberellic acid on quality potato seed production**

The experiment was conducted to find out appropriate GA₃ concentration for maximizing disease free seed potato production in Bangladesh by increasing seed tuber number per plant and accelerate seed production scheme at the research field and post graduate laboratory of Plant Pathology Department, HSTU, Dinajpur, during November 2016 to march 2017.

The experimental site, design, replication, plot size, spacing and variety were similar as described in the experiment number 1.

3.3.1. Treatments

A two factorial experiment was conducted where different size of mother seed tuber was considered as factor A and different concentration of GA₃ for the treatment of mother seed tuber was considered as factor B. The treatments combinations were as follows;

Factor A: Different size of mother seed tuber	Factor B: Different concentration of GA ₃
1. S ₁ = 15 to 25 mm diameter	1. G ₀₀ = 00 ppm
2. S ₂ = 25 to 35 mm diameter	2. G ₂₀ = 20 ppm
3. S ₃ = 35 to 45 mm diameter	3. G ₄₀ = 40 ppm
4. S ₄ = 45 to 55 mm diameter	4. G ₆₀ = 60 ppm

3.3.2. Seed collection

The foundation seeds of the variety “Cardinal” was collected from Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI). The different size potato tubers were selected in just after post cooling stage from the cold storage of Breeder Seed Multiplication Farm, Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Debiganj, Panchagarh.

3.3.3. Stock solution preparation (GA₃)

One gram GA₃ was dissolved in 70% ethyl alcohol (1 to 3 ml) and then make it volume 100 ml by adding distilled water, thus 10000 ppm GA₃ was prepared as stock solution. Then 20, 40 and 60 ppm GA₃ solutions were prepared by adding distilled water and the following formula

was used

$$V_1S_1=V_2S_2$$

Where V_1 = Volume of Stock solution, S_1 = Strength of Stock solution, V_2 = Volume of expected solution and S_2 = Strength of expected solution.

3.3.4. Preparation of planting materials and GA₃ application

The seed tubers of the potato variety “Cardinal” was taken out from the cold storage 8 days before planting. Non sprouted tuber of potato was wetted one time (40-50 ml solution per kg seed Potato) by spraying with different concentrated GA₃ solution and spread over the floor under diffused light for sprouting. The good looking, healthy and well sprouted seed tubers were used for planting.

3.3.5. Planting time of seed tuber

Planting was done on 14 November 2016.

3.3.6. Land preparation, fertilizer application, intercultural operations

Land preparation, fertilizer application, intercultural operations and statistical analysis were done as described in Experiment number 1.

3.3.7. Harvesting

The crop was haulm pulled at 82 DAP (Days after sowing), and 10 days after haulm pulling the crop was harvested. The eight plants were harvested randomly at the first time from each plot and then the rest of the plants will be harvested with help of a country plough and spade. Care was taken to avoid injury in potatoes during harvesting.

3.3.8. Data recorded

Different parameters of data were recorded as described in Experiment number 2. In addition to following data were also recorded:

The number of sprouts per tuber were counted from 5 tubers randomly and similarly total number of branches of sprouts were counted. The randomly collected 20 sprouts (single branch) were weighted. In case of the percentage leaf area coverage (LAC) data were recorded at 30, 45, 60 and 75 DAP.

3.3.9. Statistical analysis

Statistical analysis were done as described the Experiment number 1.

Experiment 4. **Degradation assessment of different categories of seed potato**

The experiment was conducted to find out the extendable generation for seed potato production in Bangladesh and degeneration percentage of seed potato at sequential years at research field of HSTU, Dinajpur, Bangladesh during winter 2014-15, 2015-16 and 2016-17 cropping seasons.

The experimental site, design, replication, plot size and spacing were done as described in the Experiment number 1.

3.4.1. Treatments

The four different categories of seed potato were used in the experiment

1. Minituber (seed potato derived from tissue culture seedling in net house)
2. Breeder seed (seed potato produced from minituber in net house)
3. Foundation seed (seed potato produced from breeder seed) and
4. Certified seed (seed potato produced from foundation seed)

3.4.2. Seed collection

The minituber, breeder seed and foundation seed tubers of potato were collected for 2014-15 cropping season from Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI). Certified seed potatoes were collected from the Bangladesh Agricultural Development Corporation (BADC), Thakorgong. The seed potato produced from 2014-15 cropping season were used in 2015-16 cropping season. Similarly, seed potato produced from 2015-16 cropping season were used in subsequent cropping season of 2016-17. The seed potato obtained from 2014-15 experiments was used for the subsequent years. During the crop seasons of 2014-15, 2015-16 and 2016-17; tuber samples preserved in the cold stored were planted in the field on November 06, 2014, November 05, 2015 and November 06, 2016, respectively. The seed potato obtained from the 2014-15 was planted in the subsequent years of 2015-16 and 2016-17, where advancement occurred in each of the generation.

Land preparation, fertilizers application and isolation distance, Preparation of planting materials and planting of seed potato intercultural operations and statistical analysis were done as described in Experiment number 2.

3.4.3. Data recorded

Data on various growth and yield related parameters such as percent germination at 30 days after planting (DAP), plant height at 60 DAP, number of stems per plant at 60 DAP, percent leaf area coverage at 60 DAP, disease incidence bacterial wilt, PVY and PLRV, yield per plant, yield, percent infected (*Rhizoctonia* canker, common scab, deformed) tuber on the basis of number and weight were recorded as the process of Experiment number 3. In addition to the following data were also calculated by the following formula.

Percentage of yield increased or decreased were calculated using the following formula:

$$\text{Yield increased or decreased (\%)} = \frac{(B-A)}{A} \times 100$$

Where, A = Yield of 1st year, B = Yield of respective subsequent 2nd or 3rd year.

Percentage of infected tuber (*Rhizoctonia* canker, Common scab, deformed) were calculated using the following formula:

$$\text{Infected tuber (\%)} = \frac{\text{Number of infected Tuber}}{\text{Number of total Tuber}} \times 100$$

3.4.4. Statistical analysis

Statistical analysis were done as described the Experiment number 1.

Experiment 5. **Effect of haulm pulling and seed size on GA₃ treated seed potato**

The experiment was conducted at the research field of Plant Pathology Department, HSTU, Dinajpur, during November 2017 to march 2018 to determine appropriate haulm pulling time of potato when the seed potatoes were treated with GA₃.

3.5.1. Treatments

The treatment combinations were as follows:

1. 35 mm to 45 mm seed tuber with 40 ppm GA₃ and haulm pulling at 75 DAP
2. 35 mm to 45 mm seed tuber with 40 ppm GA₃ and haulm pulling at 82 DAP
3. 35 mm to 45 mm seed tuber with 40 ppm GA₃ and haulm pulling at 89 DAP
4. 35 mm to 45 mm seed tuber with 40 ppm GA₃ and haulm pulling at 96 DAP
5. 35 mm to 45 mm seed tuber with 40 ppm GA₃ and haulm pulling at 103 DAP
6. 45 mm to 55 mm seed tuber with 40 ppm GA₃ and haulm pulling at 75 DAP
7. 45 mm to 55 mm seed tuber with 40 ppm GA₃ and haulm pulling at 82 DAP
8. 45 mm to 55 mm seed tuber with 40 ppm GA₃ and haulm pulling at 89 DAP
9. 45 mm to 55 mm seed tuber with 40 ppm GA₃ and haulm pulling at 96 DAP
10. 45 mm to 55 mm seed tuber with 40 ppm GA₃ and haulm pulling at 103 DAP

3.5.2. Seed collection

The different size potato tubers were selected in just after taking from the cold storage of Breeder Seed Multiplication Farm, Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Debiganj.

Land preparation, fertilizers application and isolation distance, Preparation of planting materials, planting of seed potato and intercultural operations, data collection and statistical analysis of data were done as described in the Experiment No. 3.

3.5.3. Benefit-cost analysis

The cost of production was analyzed with a view to find out the most profitable treatment combination (Islam *et al.*, 2004). In this case, all the non-material and material input costs were considered for calculating the cost of production. The details economic analysis have been presented in Appendix-XIII. The benefit cost ratio was calculated by the following formula:

$$\text{Benefit-cost ratio} = \frac{\text{Gross Return}}{\text{Total Cost of Production}}$$

3.5.4. Statistical analysis

Statistical analysis were done as described the Experiment number 1.

CHAPTER 4

RESULTS AND DISCUSSIONS

The studies in disease free seed potato production act in response to assess seed quality of farmer's seed potato, to find out the effect of different sawing and haulm pulling time, different seed potato size with different concentration of GA₃, etc. and also to assess the degradation of different categories of seed potato. Which was most remarkable and noticeable subjected to low cost quality potato seed production. However, assessment of change in growth attributes, disease infestation, quality and yield were recorded which are described in this chapter.

Experiment 1. Seed quality assessment of farmer's produced seed potato of variety Cardinal

The results of the study regarding quality assessment different sources of seed potato on diseases of potato and yield related traits and have been presented in this part.

4.1.1. Emergence of seed potato

The maximum emergence percentage (98.96) at 20 days after planting (DAP) was recorded from Positive Selection's Seeds which is statistically similar with Certified Seed and seeds of seed plot techniques (STP) and the minimum emergence percentage (89.38) recorded from Farmer's seed (Table 3). The seeds of positive selection were more vigorous than others. The result is supported by the findings of Okeyo *et al.*, (2018), where they stated that Positive Selection is a good management strategy to manage the seed borne potato viruses.

4.1.2. Plant population at haulm pulling time

The highest plant percentage (98.96) at haulm pulling time was recorded from Positive Selection's Seeds, and the lowest plant percentage (85.82) recorded from Farmer's seed (Table 1.1). On the other hand, the greatest number of plant was found in positive selection and smallest number of losses plant was found from farmer's seed. Good quality seed tuber can perform good field performance. The positive selection seed, certified seed etc. are comparatively more authentic than another and positive selection seed potatoes are collected from healthy and vigorous plants. The result is corroborated with the findings of Okeyo *et al.*, (2018) and Gildemacher *et al.*, (2007), where they stated that positive selection seed potatoes are better than normal seed tubers.

4.1.3. Tuber number per plant

The significant variation was also observed in tuber number per plant among the different sources of seed potatoes. The maximum number (8.34) of tuber per plant was observed from positive selection's seed potatoes, which is statistically similar with the plot of certified seed and Seeds of the split plot technique. The minimum number (5.96) of potatoes per plants was counted from the truthfully labelled seed tuber which was statistically similar with farmer's own seed potatoes (Table 3). The seeds of positive selection produced maximum tuber number per plant might be due to more vigorous and low disease susceptibility then other source's seed potato . The result is supported by the findings of Okeyo *et al.*, (2018). Where they stated that the field of positive selected seed potato had low visual virus incidences, higher number of tubers per hill and yield (t/ha) and low virus incidences of PVS (47%), and PVY (0.0%), PLRV (0.0%), and PVM (0.0%) were recorded and tested by ELISA from the plots of positive Selected seed potato.

Table 3. Status of different sources seed potatoes on plant population and tubers per plant

Treatments	% Emergence 20 DAP	%Emergence 30 DAP	% plants at Haulm Pulling Time	Tubers /plant
Farmer's Seed	89.38 b	97	85.42 b	6.18 b
Positive Selection's Seeds	98.96 a	100	98.96 a	8.24 a
Certified Seed	95.83 a	100	98.96 a	8.22 a
Seeds of SPT	96.67 a	100	97.92 a	7.46 a
TLS	90.62 b	99	95.83 a	5.96 b
LSD _{0.05}	4.692	NS	3.1681	1.1395
CV (%)	2.64		1.76	8.39

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.1.4. Performance of different sources seed potatoes on grading of tubers and yield

The seed potatoes of different sources were varied significantly in respect of 28-40 mm tuber per plant, 40-55 mm tuber per plant, over size tuber per plant and also yield (Table-4). Considering the tuber yield and different size tuber's weight per plant were significant. The maximum weight of "A" grade seed tuber was found from the seed of SPT which was similar with Certified and Positive Selection's Seeds. But maximum weight of "B" grade (257.26 g) tuber was found from the positive Selection's seed potato and minimum weight (198.54 g) was found in farmer's seed. The highest weight (70.31 g) of over sized seed was counted from Farmer's own seed which was similar with positive Selection's Seeds. The largest weight of tuber per plant was observed in Positive Selection's Seeds which was similar with Certified and Seeds of SPT and the smallest weight (329.48 g) was observed in farmer's seed. The

maximum yield (27.72 ton/ha) was recorded from Positive Selection's Seeds which was similar with Certified and Seeds of SPT and the smallest weight (21.97 ton/ha) was observed in farmer's seed (Table 4). The collected seed from the healthy and vigorous plant performed better yield. The result is supported by the findings of Okeyo *et al.*, (2018). Where they stated that Positive selection plots had low visual virus incidences, high number of tubers per hill and yield (t/ha).

Table 4. Performance of different sources seed potatoes on grading of tubers and yield

Treatment	Weight of tuber per plant (g)				total	Yield (ton/ha)
	10-28 mm	28-40 mm	40-55 mm	Over 55 mm		
Farmer's Seed	13.13	47.5 b	198.54 c	70.31 a	329.48 b	21.97 b
Positive Selection's Seed	17.60	76.04 a	257.26 a	64.86 a	415.77 a	27.72 a
Certified Seed	16.25	77.34 a	250.49 ab	38.59 c	382.68 a	25.51 a
Seeds of SPT	17.42	91.77 a	229.58 b	45.21 bc	383.98 a	25.60 a
TLS	9.90	54.27 b	207.29 c	62.92 ab	334.37 b	22.29 b
LSD _{0.05}	NS	16.34	22.05	18.31	34.41	2.29
CV (%)		12.51	5.12	17.24	4.95	4.95

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.1.5. Status of different source's seed potatoes on viral diseases

The field performance of different seed sources on viral diseases like potato virus Y (PVY) potato leaf roll virus (PLRV) and potato mosaic virus (PMV) are shown in Figure 1. The maximum plants (more than 8 %) were infected by PVY in Farmer's seed, but no PVY infected plants was found in the seeds of certified and Positive selection. Considering PLRV infected plant, severely infection (7.33 %) observed in farmer's seeds, where certified seeds performed lowest infection (1.04% plant). Considering PMV infected plant, severely infection (4.17 %) observed in farmer's seeds, where certified seeds performed lowest infection (1.04% plant). Seeds of SPT and TLS (truthfully labelled seed) performed more infection then certified seed in both PLRV and PMV. These results are supported by Anonymous 2012, where stated that seeds of SPT is better than farmer's seed. These results is also corroborated with Okeyo *et al.*, (2018) where they stated that Positive selection plots had low visual virus incidences.

4.1.6. Status of different source's seed potato on bacterial wilt and Black scurf

Maximum plants were infected by wilt at 60 DAP in farmer's seed, minimum plants are infected in the field of certified and seeds of SPT (Fig 2). On the other hand, highest percentage of plants infected by Black scurf (*Rhizoctonia* Canker) both in the field of positive selection seed and Certified seed. These result is supported by Anonymous 2012, they found that incidence of virus, bacteria, common scab, and late blight were very low in the trial compared to farmer's practice at neighbor plot.

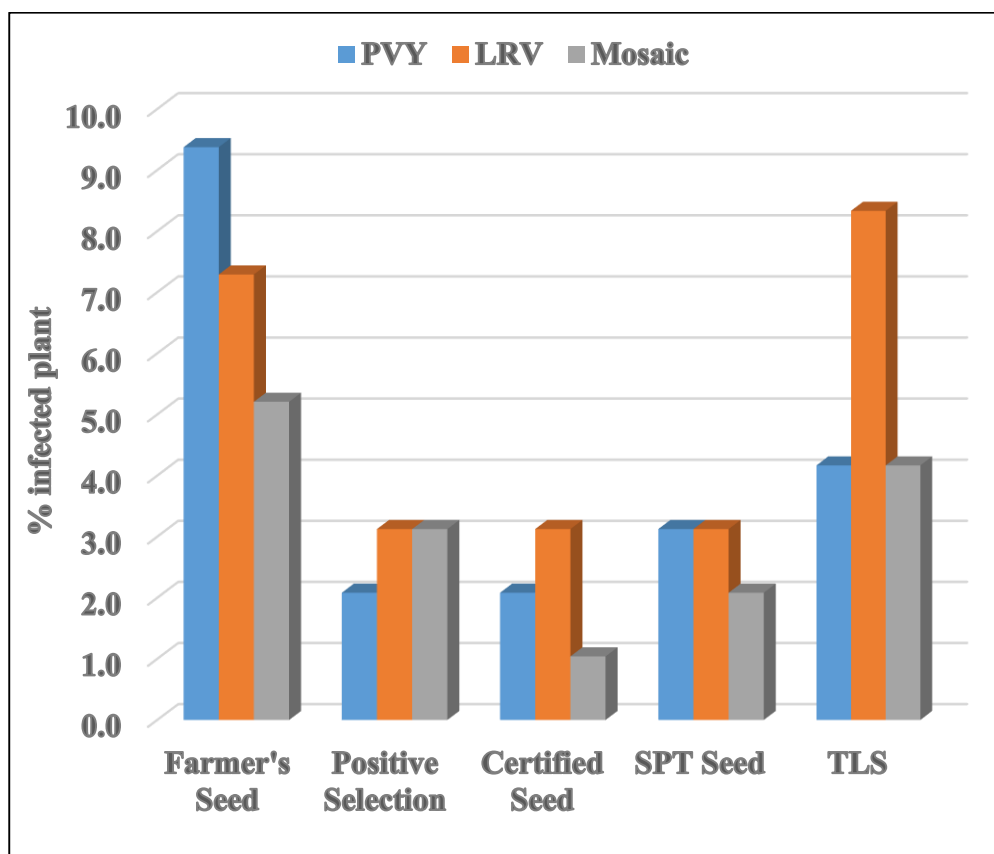


Fig 1. Status of different source's seed potato on viral diseases

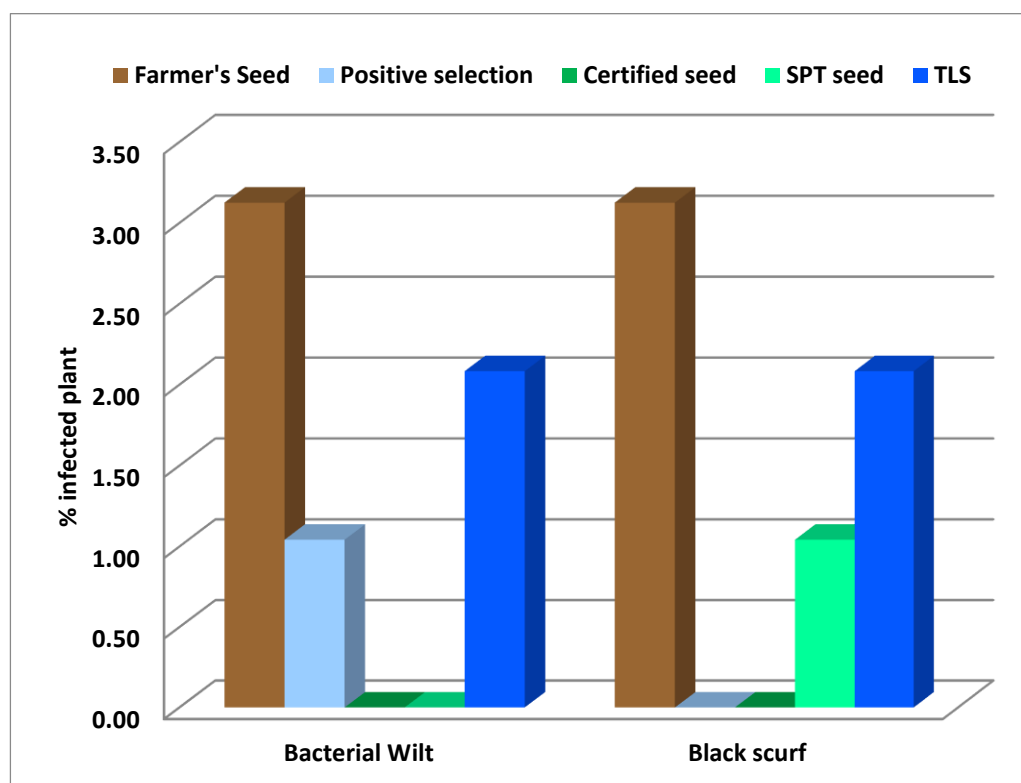


Fig 2. Status of different source's seed potato on bacterial wilt and black scurf

4.1.7. Status of different sources seed potatoes on tuber diseases and market-table Potato

Potato tubers, from the seeds of different sources, were infected significantly by *Rhizoctonia* Canker, common scab and deformed. The highest infected tuber percentage (1.39) of *Rhizoctonia* Canker found in the field of TLS which is similar with Farmer's seed. Lowest highest infected tuber percentage (0%) of *Rhizoctonia* canker found in the field of certified seeds. Considering the common scab maximum percent infected tuber recorded from Farmer's seed. In case of deformed or Physiological Disorder tuber, largest percent (7.36) was found in farmer's seeds. The lowest percent (7.36) of deformed tubers was found in certified seed, which is similar with the tubers of positive selection or SPT seeds (Table 5). These results are also supported by Anonymous (2012), where they stated that incidence of virus, bacteria, common scab, and late blight were very low in Split plot techniques plot compared to farmer's practice at neighbor plot.

Table 5. Performance of different sources seed potatoes on tuber diseases and market-table Potato

Treatments	% Infected tuber (wt basis)			% Non Marketable Tuber	%Mark et-able Potato
	<i>Rhizoctonia</i> Canker	Common Scab	Deformed		
Farmer's Seed	1.00 a	2.01	7.36 a	14.22 a	85.78 b
Positive Selection's Seeds	0.39 b	0.91	1.55 b	4.02 b	95.98 a
Certified Seed	0.00 c	0.77	1.68 b	3.36 b	96.64 a
Seeds of SPT	0.42 b	0.42	1.81 b	3.62 b	96.38 a
TLS	1.39 a	1.56	6.65 a	12.54 a	87.46 b
LSD _{0.05}	0.56	1.37	2.70	5.97	5.97
CV (%)	46.73	53.59	37.65	42.01	3.43

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Farmer's seeds are infected with different diseases and so that maximum percent (14.22) Potato tubers become non marketable and minimum percent (85.78) Potato tubers become marketable among the treatments. On the other hand, minimum non Marketable percent (3.36) tubers and minimum marketable (96.64) percent produced by certified seeds which is similar with positive selection or SPT seed potato.

Experiment 2. **Effect of different planting and haulm pulling time on quality and health of seed potato**

The results of the study regarding the effect of different sowing time and haulm pulling time on disease free seed tuber production and growth characters, yield, yield related traits and diseases of potato have been presented in this chapter.

4.2.1. Effect of sowing time on seed potato emergence

Percent seed potato emergence at different dates of data collection differed significantly (Table 6). At 20 DAP, the maximum 88.02% seed potato emergence was recorded when the seed was sown at 14th December, which was similar with 4th November. Seed potato emergence percentage was increased when data was recorded at 30 DAP. The maximum 100% emergence was recorded at seed sowing time of 4th November, 24 November and 14 December and the minimum 74.48 % seed emergence was observed when the seed was sown at 15 October. The findings of the present study indicate that the seed emergence of potato had no effect at sowing time of early November to mid-December. Similar results was also reported by Afsana (2018) where she recorded the maximum 99.7% seed emergence at seed sowing time of 1st November and minimum 88.5% was in sowing time of 2nd October. Comparatively soil moisture and temperature in the November is congenial to potato cultivation in Bangladesh that enhances the seed emergence and better plant growth. Jamro *et al.*, (2015) found maximum 84.95% seed emergence of potato at sowing time of 30th October. The earliest planting date of 30th September in Maharastra, India recorded maximum emergence of potato at 15 and 30 DAP reported by Thongam *et al.*, (2017). On the other hand the early planting of potato in October 20 delayed emergences was reported by Bewuketun *et al.*, (2015). Alam *et al.*, (2017) reported that from 31 October to 30 November plantation time is suitable for seed emergence of potato in Bangladesh.

4.2.2. Influence of sowing time on plant height (cm) and stem number per hill at different dates of observations

The plant height (cm) was varied significantly at 30, 45, 60 days after planting and at haulm pulling time (Table 7). At 30 DAP the maximum (30.20 cm) plant height was recorded at sowing time of 4th November that was similar with sowing time of 15th October (28.01 cm)

Table 6. Effect of sowing time on emergence of seed potato at different dates after planting

Sowing time	% Emergence 20 DAP	% Emergence 30 DAP
15 th October	61.46 (4.33) b	74.48 (4.77) b
04 th November	79.69 (4.94) a	100.00 (5.54) a
24 th November	65.10 (4.40) b	100.00 (5.54) a
14 th December	88.02 (5.19) a	100.00 (5.54) a
LSD _{0.05}	0.4088	0.1257
CV%	10.4	2.82

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. Figures in parenthesis indicate transformed (1st column Arcsine, 2nd column Square root) value

which was followed by 14th December (21.35 cm). On the other hand the minimum plant height (15.93 cm) was observed when data was recorded at 24th November. At 45 DAP and 60 DAP there were no significant differences was found at plant height among the sowing times. But, the plant height at haulm pulling time was significantly influenced by date of planting. The result showed that plant height decreased as the advancement of date of planting. The planting time of 15th October was recorded the highest plant height (56.78 cm) which was similar with the planting time of 4th November and 24th November; whose differed in compared to 14th December planting dates (Table 7). These differences in plant height can be attributed to the differences in the prevailing weather conditions. The highest plant height at the planting time of 15th October can be attributed to the most favorable environment i.e. long period of high temperature for plant growth during the cropping season. The lowest plant height (47.25 cm) was recorded at the planting time of 14th December can be due to the lower temperature experienced by the plants after emergence compared to other planting dates, thus lower temperature might have reduced allocation of assimilates for growth than the remaining three planting dates, and higher temperature experienced by the plants after 50-55 DAP compared to other planting dates. Similar findings have also been reported by Sandhu *et al.*, (2012), and Ezekiel and Bhargava (1992), Alam *et al.*, (2017), Afsana (2018) and Monsor^a (2014).

The results showed that the stem number per hill was influenced by different planting time (Table 7). At 30 DAP the maximum number (5.47) of stem per hill was observed when the seed was sown at 14th December which was similar to seed planting of 4th November. The minimum number (2.77) of stem per hill was counted when the seed was sown at 15th October. At 45 DAP the maximum number (5.60) of stem per hill was observed when the seed was sown at 14th December, which was similar with 4th November and 24th November. The minimum number (2.88) of stem per hill was recorded when the seed was sown at 15th October. The similar trend of branching was observed at 60 DAP. At haulm pulling time of potato plants, the

maximum number (5.17) of stem per hill was observed when the seed was sown at 4th November which was similar with 24th November and 14th December. On the other hand the minimum number (2.77) of stem per hill was recorded when the seed was sown at 14th October. As per results of Alam *et al.*, (2017), there was no significantly influence on stem per hill by early to late November dates of planting of potato. The stem number per plant was differed on the basis of very early planting time (Mid October) with other planting time (November to Mid. December), according to Afsana (2018) and Bewuketun *et al.*, (2015).

Table 7. Effect of sowing time on plant height and stem per hill of potato at different dates after planting

Sowing Time	Plant height (cm)				Stem per hill (No.)			
	30 DAP	45 DAP	60 DAP	HP time	30 DAP	45 DAP	60 DAP	HP time
15 th October	28.01 a	39.85	52.77	56.87 a	2.77 c	2.88 b	2.95 b	2.77 b
04 th November	30.20 a	43.83	50.57	52.32 a	5.40 a	5.38 a	5.47 a	5.17 a
24 th November	15.93 c	41.43	52.53	53.45 a	4.67 b	4.92 a	5.03 a	4.95 a
14 th December	21.35 b	41.62	47.43	47.25 b	5.47 a	5.60 a	5.63 a	5.12 a
LSD _{0.5}	5.17	NS	NS	4.88	0.72	0.72	0.71	0.70
CV%	25.99	16.04	11.56	11.16	18.93	18.42	17.83	18.66

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

HP time = Haulm pulling time, DAP = Days after planting

4.2.3. Effect of planting time on leaf area coverage (LAC) and canopy weight

Percent leaf area coverage (LAC) was varied significantly at 30, 45, 60 Days after planting (DAP). Regarding 30 DAP, the highest LAC (52.75 %) was found at the planting time of 04th November which was followed by 14th December (25.83%). But, the lowest LAC (21.08 %) was found at the planting time of 24th November. At the 1st week of November, there was suitable potato growing environment and cause large LAC. At 45 DAP, the highest LAC (72.58 %) was found at the planting time of 4th November which was similar with 24th November and 14th December. The lowest LAC (47.42 %) was found at the planting time of 15th October. The similar trends of % LAC of potato were observed at 60 DAP. The different planting time was not affect significantly on LAC at haulm pulling time (Table 8). Comparatively highest plant height with maximum stems per plant is responsible for higher canopy coverage. The result is supported by finding of Alam *et al.*, (2017) and Anonymous^a (2011-12).

The different planting time on canopy weight (g) per plant was varied significantly (Table 8). The planting time of 4th November with canopy weight 209.67 g per plant was higher than other planting times. The lowest canopy weight 68.92 g per plant was recorded at the planting time of 14th December. The winter season in Bangladesh, mainly from November to early

February, was best environmental condition for proper growth and development of seed potato, so early November planting time performed better in canopy weight per plant due to find longer winter for life cycle and can synthesis and accumulate more carbohydrates in the canopy. The result is supported by the finding of Alam *et al.*, (2017) and Anonymous^a (2011-12) where they stated that in Bangladesh, the planting at November is most suitable for vegetative development and yield of potato.

Table 8. Effect of planting time on leaf area coverage (LAC) and canopy weight of potato at different growth stage

Planting time	Leaf Area Coverage (%)			HP Time	Canopy wt/pl(g)
	30 DAP	45 DAP	60 DAP		
15 th October	21.58 (26.50) b	47.42 (41.79) b	61.08 (49.84) b	59.25	103.67 c
04 th November	52.75 (44.95) a	72.58 (56.56) a	89.50 (69.19) a	68.08	209.67 a
24 th November	21.08 (26.06) b	72.00 (56.14) a	88.67 (68.22) a	64.08	164.42 b
14 th December	25.83(29.20) b	79.75 (61.40) a	83.67 (64.18) a	66.08	68.92 d
LSD _{0.5}	3.83	5.44	5.81	NS	31.24
CV%	14.49	12.08	11.08		27.42

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Figures in parenthesis indicate transformed (Arcsine) value

4.2.4. Effect of different haulm pulling (HP) time on LAC and canopy weight

The different haulm pulling time on the leaf area coverage was significant (Table 9). The highest LAC (79.67%) was found in the haulm pulling of 68 DAP which was similar with the haulm pulling of 75 DAP and followed the haulm pulling of 82 DAP. The lowest LAC (40.83 %) was found in the haulm pulling of 89 DAP. Delaying haulm pulling time decrease the LAC of potato due to after vegetative stage or from maturity stage the plants are dried and weathered day by day. This result is supported by Anonymous^a (2011-12).

Effect of haulm pulling times on the canopy weight per plant was varied significantly (Table 9). The highest weight (181.83 g) of canopy per plant was counted from the haulm pulling time of 75 DAP which was similar with 68 DAP and followed 82 DAP. The lowest weight (60.25 g) of canopy per plant was found from the haulm pulling of 89 DAP. Higher leaf area coverage may cause higher canopy weight, which is regulated by plant height and branch number per plant. Delaying haulm pulling time reduce the water content, defoliate the leaves and stems, and may transferred the starch contents to tubers and decrease the canopy weight. This result is supported by the findings of Thongam *et al.*, (2017), Alam *et al.*, (2017) and Jamro *et al.*, (2015), where they stated that ground coverage is related to the plant height and leaves number per plant.

Table 9. Effect of different haulm pulling (HP) time on LAC and canopy weight of potato

Haulm Pulling Time	% LAC at HP time	Canopy weight/plant (g)
68 DAP	79.67(61.53) a	177.67 a
75 DAP	74.58(58.14)a	181.83 a
82 DAP	62.42(50.80)b	126.92 b
89 DAP	40.83(38.01)c	60.25 c
LSD _{.5}	6.52	31.24
CV%	15.00	27.42

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. Figures in parenthesis indicate transformed (Arcsine) value.

4.2.5. Effect of planting time on late blight of potato

Late blight (LB) of potato was observed at 1st week of January 2017 due to presence of low temperature and foggy weather (Table 10). The data revealed that different planting time on natural LB development at 05 January 2017 was varied significantly among the observations. Maximum late blight infestation (2.90%) and LB severity i.e. PDI (21.81) was recorded in planting time of 24th November while planting time of 14th December had significantly less amount of late blight infestation (0.29%) and LB severity or PDI (13.09). The highest (21.81) PDI was recorded at the planting time 24th November. At 5th January, plants were at growth stage of 82, 62, 42 and 22 days in respect of chronological different planting time.

At 11th January 2017, infection percent and PDI of late blight was recorded, the highest at the planting time of 24th November that was followed by 4th November and 14th December. The lowest infection percent and PDI of late blight was recorded at the planting time of 15th October.

At 18th January 2017, the highest LB infestation and PDI was also recorded at planting time of 24th November. On the other hand the lowest LB infestation and PDI was also recorded at the planting time of 15th October (Table 10). The late planting (before December) showed first appearance of late bight and rapid progress of late blight. The results are in conformity with findings of Afsana (2018) and Singh and Pundhir (2012) in which they stated that different planting times influence late blight development of potato.

Table 10. Effect of different planting time on late blight (LB) development and after control

Planting time	05 January 2017		11 January 2017		18 January 2017	
	%LB	PDI	%LB	PDI	% Disease	PDI
15 th October	0.46 (1.07) c	13.74 c	0.42 (1.04) c	13.41 c	0.00 (0.84) c	12.50 b
04 th November	1.29 (1.40) b	17.25 b	1.74 (1.52) b	17.97 b	1.54 (1.39) b	17.58 b
24 th November	2.90 (1.88) a	21.81 a	3.08 (1.94) a	25.13 a	6.25 (2.63) a	30.47 a
14 th December	0.29 (0.99) c	13.09 c	1.68 (1.53) b	16.60 b	1.87 (1.58) b	17.64 b
LSD _{0.5}	0.15	1.30	0.28	2.01	0.39	4.59
CV%	13.58	9.43	11.18	13.19	14.58	14.1

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Figures in parenthesis indicate transformed (Square root) value,

4.2.6. Effect of planting time on PLRV, PMV, PVY, wilt and Heat Injury

The effect of different planting time on the naturally occurred potato leaf roll Virus (PLRV) was significant at only haulm pulling time. The maximum percentage (4.17%) of PLRV was identified at 4th November planting time which was similar with 15th October. The minimum percentage (0.52 %) of PLRV was identified at 14th December. In case of Potato Mosaic Virus at 45 DAP, there were significant variations. The maximum percentage (2.60%) of PMV was identified at 24th November planting time which was followed by 4th November. At haulm pulling time, the highest percentage (9.38%) of PMV affected plants was counted from 24 November which was followed by 14th December. In case Potato Virus Y, at 60 DAP, maximum infected plants (2.08%) of PVY were identified from 24th November planting time which was followed by 4th November. But, at haulm pulling time, the highest percentage (1.04%) of PVY affected plants was counted from 4th November (Table 11). Delaying planting time of potato in Bangladesh, ensure climate warm in vegetative stage of potato and increase the potato virus disease due to vector (aphid) spread in the field. These results are agreement with the finding of Monsor^a (2014), Rahman and Akanda (2010), Halim (1999) and Afsana (2018).

The incidence of bacterial wilt of potato plants varied significantly in different planting time observed (Table 11). The 14th December planting time performed highest (47.92%) bacterial wilt infected plant at Haulm pulling time. But the minimum (4.17 %) wilt incidence was observed when the seed was sown 15th October. The result is supported by the finding of Anonymous (2015) and Anonymous (2017) where they stated that the wet and

warm conditions (temperature 25 – 30° C) are favorable for the development of Bacterial wilt disease, and it depends on the environmental conditions and age of the host.

The effect of different planting time on the Heat injury was varied significantly. Only at the planting time of 14th December showed heat injury (Table 11). Daley planting time, mid-December, increase the wilt and heat injury due to heavy sunshine and warmed weather from 2nd week of February when the plants were at vegetative stage (55 days). These results are supported by the findings of Wahid *et al.*, (2007) and Rykaczewska, (2013).

Table 11. Effect of planting time on PLRV, PMV, PVY, wilt and Heat Injury

Planting time	PLRV		PMV		PVY	% Wilt	Heat injury
	45 DAP	HP	45 DAP	HP	45 DAP	HP	68 DAP
15 th October	0.00	3.13 a (1.67)	0.00 b (0.84)	0.00 b (0.84)	0.00 b (0.84)	4.17 b (1.07)	0.00 b (0.84)
04 th November	0.52	4.17 a (1.97)	0.52 b (0.99)	1.04 b (1.14)	1.56 ab (1.29)	14.06 b (1.50)	0.00 b (0.84)
24 th November	0.52	2.60 b (1.52)	2.60 a (1.46)	9.38 a (2.89)	1.56 ab (1.52)	16.15 b (2.09)	0.00 b (0.84)
14 th December	0.52	0.52 c (0.99)	0.00 b (0.84)	3.13 b (1.60)	3.12 a (1.74)	47.92 a (6.40)	8.85 a (2.97)
LSD _{0.05}		0.41	0.25	0.43	0.61	1.46	0.55
CV%	NS	65.33	59.22	65.15	54.56	31.55	23.86

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Figures in parenthesis indicate transformed (Square root / Arcsine) value

HP =Haulm pulling time and DAP= Days after sawing

4.2.7. Effect of haulm pulling time on PLRV, PMV, PVY, wilt and heat injury of potato

The effect of different haulm pulling time on the naturally occurred potato leaf roll Virus (PRLV), Potato Mosaic Virus (PMV) and Potato Virus Y (PVY) was significant (Table 12). The maximum infected plants ((PRLV 3.13%, PMV 4.69% and PVY 2.6 %) were recorded from late haulm pulling (89/82 DAP) and the minimum infected plants ((PRLV 1.56%, and PVY 0 %) were recorded from early haulm pulling (68 DAP). Increasing haulm pulling time, increase the viral diseases of potato by spreading the vector. These results are agreement with the finding of Monsor^b (2014) and Struik & Wiersema (1999). Khurana (2008) reported that knowledge about the potato viruses helps in their detection/elimination and methods of integrated control to avoid their spread in nature i.e. adjustment of harvesting time will helpful for the growers.

The incidence of bacterial wilt of potato plants varied significantly in different Haulm pulling time (Table 12). The highest (43.23 %) bacterial wilt infected plant was found in late Haulm pulling at 89 DAP which is similar with at haulm pulling time 82 DAP. Minimum (9.38%) plant were wilted when haulm pulling early (68 DAP or 75 DAP). If haulm pulling is delayed, the environmental temperature is increased. So the incidence of wilting is enhanced. The result is supported by the finding of Anonymous (2015) where it was stated that the wet and warm conditions are favorable for the development of Bacterial wilt disease, and it depends on the factors of host species, environmental conditions, age of the host and the resistance of the host. According to Anonymous (2017), Bacterial wilt disease development is favored by warm temperatures (25–30°C) and is limited by temperatures below 10°C. Soil moisture is important as the bacterium cannot tolerate dry soil conditions.

Different haulm pulling time significantly varied the Heat injury of late potato. The maximum (3.65%) plants were injured by heat at the time of haulm pulling 89 DAP which was similar with 82, 75 DAP. The minimum (1.04%) plants were injured by heat at the time of haulm pulling 68 DAP (Table 12). From last week of January, the temperature is increased rapidly which directly affect development of crop of mid-December planting time. These results are corroborated with the finding of Wahid *et al.*, (2007) and Rykaczewska. (2013). According to Wahid *et al.*, (2007), the transitory or constant high temperatures cause an array of morphoanatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield. According to Rykaczewska (2013), the response of potato plants to high temperature during the growing season is dependent on the growth stage. The impact of high temperature 32°C/25°C on potato plants was more negative on the growth and yield of potato.

Table 12. Effect of haulm pulling time on PLRV, PMV, PVY, wilt diseases and heat injury of potato

Planting time	PLRV (%)	PMV (%)	PVY (%)	Wilt (%)	Heat injury (%)
68 DAP	1.56 (1.29) c	3.12 (1.61) a	0.00 (0.84) b	9.38 (1.67) b	1.04 (1.14) b
75 DAP	2.60 (1.40) b	2.08 (1.37) b	1.04 (1.14) ab	10.94 (2.17) b	2.08 (1.37) a
82 DAP	3.13 (1.24) a	3.65 (1.69) a	2.60 (1.59) a	18.75 (3.00) a	2.08 (1.37) a
89 DAP	3.13 (1.34) a	4.69 (1.81) a	2.60 (1.59) a	43.23 (4.22) a	3.65 (1.60) a
LSD.5	0.41	0.43	0.61	1.46	0.55
CV%	65.33	65.15	54.56	31.55	23.86

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. Figures in parenthesis indicate transformed (Square root /Arcsine) value.

4.2.8. Effect of planting times on yield and yield component of potato

The different planting times significantly affected total tuber number and weight per plant, seed-tuber number and weight per plant, potato yield and seed-potato yield (Table 13). The maximum tuber number (11.07) was counted from the late planting time ie. 14th December which was followed by 4th November and the minimum number (7.33) of tuber was found in 24th November.

The highest number of seed-tubers per plant (7.65) was recorded from the planting time 14th December which was similar with 4th November (6.92) and followed by 24th November (5.93). The lowest number of seed-tubers per plant (4.63) was collected from the 15th October. In case of the planting at 14th December, the seed tubers were collected before 20 days of planting time. So the collected seeds were de-sprouted for one time before final sprouting. For these reason, stem number per plant and tuber number per hill was increased.

The maximum weights (400.23 g) of total tuber per plant were recorded from the planting time of 4th November which was similar with the planting time of 24th November. The minimum weight (332.07 g) of tuber was observed in the planting time of 15th October which was similar with the planting time 14th December. Similar trend of results also counted at potato yield. The maximum potato yield (24.28 ton/ha) was recorded from 4th November which was identical with 24th November. The lowest yield (15.31 ton /ha) was recorded from the planting time of 15th October. Considering seed (28-55 mm size tuber) potato per plant, significant variation also found in different planting time. The highest weight (342.77 g) per plant was recorded from 4th November which was similar with 24th November. The minimum weight (217.77 g) counted from 15th October (Table 13). These results are consistence with many workers (Thongam *et al.*, (2017), Alam *et al.*, (2017), Monsor^a (2014)¹, Sajeda *et al.*, (2013), Bahram *et al.*, (2012), Hasanpanah *et al.*, (2009), Kawakami *et al.*, (2005) and Iritani *et al.*, (1983)) reported that different planting dates influenced tuber number and yield of potato.

4.2.9. Effect of haulm pulling times on yield and yield component of potato

In case of the total number of tuber per plant, the highest number (9.78) was found in 82 DAP which was similar with 75 and 89 DAP. The minimum number (8.15) of total seed tuber was recorded from the haulm pulling time of 68 DAP (Table 13). Similar results were observed by Alam *et al.*, (2017), Monsur^b (2014) and Bahram *et al.*, (2012), and found that harvesting dates influenced tuber number per plant significantly.

The maximum weight (385.20 g) of total tuber were recorded from the haulm pulling time at 82 DAP which was statistically similar with 75 and 89 DAP. The minimum weight (285.80 g) of tuber were observed from the haulm pulling at 68 DAP. The maximum potato yield (22.02 ton/ha) was recorded from the haulm pulling at 89 DAP which was similar with haulm pulling at 82 and 75 DAP. The lowest yield (17.45 ton /ha) was recorded from haulm pulling at 68 DAP. The maximum seed yield (18.41 ton/ha) was recorded from haulm pulling at 82 DAP which was similar with haulm pulling at 89 and 75 DAP. The lowest yield (15.94 ton /ha) was recorded from haulm pulling at 68 DAP (Table 13).

The potato plants were matured completely at 75 DAP and decrease the carbohydrate accumulation rate. So, the tuber number per plant was similar at 75 to 89 DAP, but 68 DAP. Similar results was observed by Alam *et al.*, (2017), Monsor^b (2014)², Sandhu *et al.*, (2012), Bahram *et al.*, (2012), Virtanen and Seppanen (2014) and Hussain (1992) who reported that harvesting dates influenced yield of potato.

4.2.10. Interaction effect of Planting and haulm pulling time on yield and yield components of potato

The interaction effect of different Planting and haulm pulling time in production of tubers/plant, tuber weight /plant, yield and seed yield were different significantly (Table 13). In case of the total number of tuber per plant, the highest number (12.27) was found in planting time of 14 December with HP time of 82 DAP and the lowest number (6.40) of total tuber was recorded from the 14 October with HP 68 DAP. But no variation was found in seeds per plant and seed weight per plant. The maximum weight (466.47 g) of total tuber were recorded from 4 November with 75 DAP and the minimum weight (265.47 g) of tuber were observed in 14 October with 68 DAP. The maximum potato yield (29.23 ton/ha) was recorded from 24 November with HP 89 DAP and the lowest yield (12.26 ton /ha) was recorded from 14 October with HP 68 DAP. The maximum seed potato yield (23.87 ton/ha) was recorded from 4 November with 82 DAP. The lowest seed yield (10.83 ton /ha) was recorded from 14 October with HP 89 DAP. Similar results was observed by Alam *et al.*, (2017) and Jamro *et al.*, (2015) and reported that planting and harvesting dates influenced tuber number and yield of potato.

4.2.11. Grading of potato

4.2.11.1. Effect of different planting time on grading of potato

The smallest sized (10 - 28 mm) tuber weight was not varied significantly, but tuber number was different among the treatments of different planting time. The maximum smallest tuber number per plant (3.42) was produced from the planting time of 14th December which were statistically differ from other three date of planting times. Considering 28 - 40 mm or A grade tuber per plant, it was statistically significant among different treatments both weight and number basis. The highest weight (201.55 g) and number 5.95 of “A” grade tuber was counted from 14 December which was followed by the planting time of 4th November and 24th November. The lowest weight (73.82 g) and number (2.25) of “A” grade tubers was recorded from the planting time of 15th October. Regarding “B” grade (40 -55 mm) tuber production, maximum weight (218.5 g) and number (2.82) of “B” grade tubers was produced from the planting time of 4th November which was statistically similar with the planting time of 15th October and 24th November. In case of over size (> 55 mm) tuber, the largest weight (45.7) and number (0.30) of tubers were recorded from the planting time of 15th October and no over Sized tubers were found in the planting time of 14th December (table 14). Different planting time influenced different grades of potato was reported by Monsur^a (2014).

Table 13. Effect of planting and haulm pulling times on yield and yield component of potato

A. Planting time	Tubers /plant	Seeds/ plant	Tuber wt/plant	Seed weight / plant (g)	Yield (ton /ha)	Seed Yield(t/ha)
15 th October	7.33 c	4.63 c	332.07 b	271.77 b	15.31 b	12.32 c
04 th November	9.70 b	6.92 a	400.23 a	342.77a	24.28 a	20.85 a
24 th November	8.27 c	5.93 b	358.10ab	315.58a	24.28 a	21.51 a
14 th December	11.07 a	7.65 a	332.88 b	303.23ab	17.38 b	15.85 b
LSD _{0.5}	1.15	NS	44.78	39.80	3.92	1.99
B. Haulm pulling at						
68 DAP	8.15 b	4.63	285.80 b	260.87 b	17.45 b	15.94 b
75 DAP	9.13 ab	6.92	376.27 a	337.18 a	20.19 a	18.11 a
82 DAP	9.78 a	5.93	385.20 a	325.85 a	21.59 a	18.41 a
89 DAP	9.30 ab	7.65	376.02 a	309.45 a	22.02 a	18.07 a
LSD _{0.5}	1.15	0.89	44.78	39.80	3.92	1.99
Interaction A&B						
14 th Oct.+ 68 DAP	6.40 f	4.2	265.47 e	245.93	12.26 h	11.43 ef
14 th Oct. +75 DAP	7.40 d-f	5.9	360.07 b-e	260.67	15.84 gh	14.79 c-f
14 th Oct. + 82 DAP	8.07 c-f	5.2	363.13 b-e	254.27	15.68 gh	12.24 d-f
14 th Oct.+ 89 DAP	7.47 d-f	7.7	339.60 b-e	282.60	17.47 fg	10.83 f
4 th Nov.+ 68DAP	8.47 b-f	5.3	296.33 de	335.67	20.02 d-g	17.67 bc
4 th Nov. + 75DAP	9.80 a-e	7.3	466.47 a	384.67	25.79 a-c	21.31 ab
4 th Nov. + 82DAP	10.53 a-c	6.5	428.67 ab	329.40	27.34 ab	23.87 a
4 th Nov. + 89DAP	10.00 a-d	7.1	409.47 a-c	299.00	23.96 b-d	20.57 ab
24 th Nov.+ 68DAP	7.20 ef	4.7	273.47 e	285.47	20.64 d-f	19.2 bc
24 th Nov. + 75DAP	8.93 b-f	7.5	349.40 b-e	374.20	22.06 c-e	20.80 ab
24 th Nov. + 82DAP	8.27 c-f	5.7	400.47 a-d	333.20	25.17 a-c	21.29 ab
24 th Nov. + 89DAP	8.67 b-f	7.7	409.07 a-c	310.53	29.23 a	24.73 a
14 th Dec. + 68DAP	10.53 a-c	4.3	307.93 c-e	220.00	16.86 fg	15.47 c-e
14 th Dec. + 75DAP	10.40 a-c	7.0	329.13 b-e	351.53	17.07 fg	15.51 c-e
14 th Dec. + 82DAP	12.27 a	6.3	348.53 b-e	345.47	18.17 e-g	16.26 cd
14 th Dec. + 89 DAP	11.07 ab	8.1	345.93 b-e	320.80	17.41 fg	16.17 cd
LSD _{0.05}	4.21	NS	163.45	NS	7.15	7.25
CV%	15.21	16.9	15.09	15.48	11.56	13.52

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.2.11. 2. Effect of different haulm pulling time on grading of potato

The effect of different haulm pulling time on “B” grade (40 - 55 mm) tuber and oversize (< 55mm) tuber per plant were varied significantly (Table 14). Haulm pulling at 75, 82 and 89 DAP produced the higher weight (205.3, 208.6, 182.3 g) and number (2.65, 2.60 and 2.50) of “B” grade tuber respectively. The lowest weight (192.6 g) and number (1.72) of “B” grade tubers was recorded from the haulm pulling time of 68 DAP. Moreover, maximum weight (45.65 g) and number (0.32) of over size tubers were recorded from the haulm pulling time of 89 DAP. The lowest tuber weight (4.10 g) and number (0.03) per plant of over size seed tubers were collected from the haulm pulling time of 68 DAP. Similar results were observed by Alam *et al.*, (2017) and Monsor^b (2014).

4.2.11.3. Interaction effect of planting time and haulm pulling time on grading of potato

Combined effect of different planting time and haulm pulling time on tuber grading of both weight and number basis in 28 - 40 mm (“A” grade), 40 - 55 mm (“B” grade) and oversize tuber (>55 mm) were significant (Table 14). In response of 28 -40 mm (“A” grade) sized tuber, the highest weight (226.2 g) and number (6.8) was counted from 14th December with HP 68 DAP and the lowest weight (64.80 g) of seed tubers was recorded from 14th October with HP 89 DAP, but minimum tubers (2.0) were produced from 14th October with HP 68 DAP. Maximum weight (254.4 g) of “B” grade (40 – 55 mm) tuber was counted from 24th November with HP 82 DAP and the lowest weight (56.40 g) of “B” grade tubers was recorded from 14th December with HP 68 DAP. But, the maximum number (3.13) of “B” Grade tuber was produced from the 4th November with HP 75 DAP and the minimum number (0.87) of “B” grade tuber was recorded from 14th December with HP 68 DAP. Considering the over size tubers, the maximum weight (102.9 g) and number (0.67) were recorded from 14th October with 89 DAP, but no over size tuber was counted from the planting time 14th December with any HP time and 24th November with HP 68/75 DAP (Table 14).

4.2.12. Effect of planting times on tuber’s common scab and *Rhizoctonia* canker

The different planting time had significant effect on common scab of potato (Table 15). The disease incidence (25.16%) and PDI (Percent Disease Index) (42.55) of common scab were highest in the field of planting time 15th October and the lowest incidence percentage (10.06) and PDI (Percent Disease Index) (13.03) of common scab was in planting time 14th December (Table 15). From the result it was revealed that delay planting time decrease common scab of potato. The results are just altering the results of Waterer (2002), who reported that the planting and harvest dates were influenced the yields and grade-out due to tuber damage by common scab (*Streptomyces* spp.). The optimum temperature for growth of *S. scabies* is relatively high

Table 14. Effect of different planting time and haulm pulling time on grading of potato per plant

Treatments	10-28 mm (below size)		28-40 mm (A grade)		40-55 mm (B grade)		> 55mm (Over size)	
	Wt.(g)	Number	Wt.(g)	Number	Wt.(g)	Number	Wt.(g)	Number
A. Planting times								
15 th October	14.6	2.40 b	73.8 c	2.25 c	198.0 a	2.38 a	45.7 a	0.30 a
04 th November	40.2	2.65 ab	124.3 b	4.10 b	218.5 a	2.82 a	17.2 b	0.13 bc
24 th November	19.1	2.18 b	107.8 b	3.37 b	207.8 a	2.57 a	23.5 ab	0.15 b
14 th December	29.7	3.42 a	201.6 a	5.95 a	101.7 b	1.70 b	0.0 b	0.00 c
LSD _{0.5}	NS	0.88	27.21	0.89	36.31	0.46	23.74	0.14
B.Haulm pulling Times								
68 DAP	20.8	2.37	131.3	4.03	129.6 b	1.72 b	4.1 b	0.03 b
75 DAP	34.3	2.55	131.9	3.90	205.3 a	2.65 a	4.8 b	0.03 b
82 DAP	27.5	3.17	117.2	3.82	208.6 a	2.60 a	31.8 a	0.20 a
89 DAP	20.9	2.57	127.2	3.92	182.3 a	2.50 a	45.7 a	0.32 a
LSD.5	NS	NS	NS	NS	36.31	0.46	23.74	0.14
Interaction A&B								
14 th Oct. 68 DAP	11.1	2.13	72.1 de	2.00 g	173.9a-e	2.20 a-d	8.5 bc	0.07 cb
14 th Oct. 75 DAP	13.5	2.07	82.9 c-e	2.40 e-g	252.7 a	2.87 a-d	10.9 bc	0.07 cb
14 th Oct. 82 DAP	17.1	2.93	75.5 c-e	2.33 e-g	210.0 a-c	2.40 a-d	60.5 ab	0.40 ab
14 th Oct. 89 DAP	16.7	2.47	64.8 e	2.27 e-g	155.2 b-e	2.07 a-d	102.9 a	0.67 a
4 th Nov. 68DAP	27.7	2.47	107.5c-e	3.93 c-g	153.2 b-e	2.00 a-d	7.9 bc	0.07 cd
4 th Nov. 75DAP	73.4	2.47	135.9 bc	4.13 b-f	248.7 a	3.13 a	8.4 bc	0.07 cd
4 th Nov. 82DAP	35.3	2.93	129.7 b-d	4.40 b-e	244.5 a	3.07ab	19.2 bc	0.13b-d
4 th Nov. 89DAP	24.5	2.73	124.1 b-e	3.93 c-g	227.5 ab	3.07ab	33.4 bc	0.27 b-d
24 th Nov. 68DAP	19.2	2.00	119.3 c-e	3.40 d-g	135.0 c-f	1.80 b	0.0 c	0.00 d
24 th Nov. 75DAP	20.0	2.40	128.0 b-e	3.87 c-g	201.4 abcd	2.67a-d	0.0 c	0.00 d
24 th Nov. 82DAP	19.7	2.27	78.8 c-e	2.80 e-g	254.4 a	2.93 a-c	47.5 bc	0.27 b-d
24 th Nov. 89DAP	17.3	2.07	105.3 c-e	3.40 d-g	240.2 a	2.87a-d	46.3 bc	0.33 bc
14 th Dec. 68DAP	25.3	2.87	226.2 a	6.80 a	56.4 f	0.87 e	0.0 c	0.00 d
14 th Dec. 75DAP	30.1	3.27	180.5 ab	5.20 a-d	118.5ef	1.93 cd	0.0 c	0.00 d
14 th Dec. 82DAP	38.0	4.53	185.0 ab	5.73 a-c	125.5 d-f	2.00 b-d	0.0 c	0.00 d
14 th Dec. 89 DAP	25.1	3.00	214.5 a	6.07 ab	106.3 ef	2.00 b-d	0.0 c	0.00 d
LSD _{0.05}	NS	NS	99.30	3.27	132.533	1.6702	86.64	0.50
CV%			25.72	27.4	24.00	23.19	131.82	112.56

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

(25-30°C) and losses to scab are more severe in warm regions or growing seasons (Hooker 1981; Loria *et al.*, 1997). Timely planting of potato to reduce the crop's exposure to temperatures suited to growth of the scab lesions may reduce crop losses, providing it does not excessively interfere with productivity of the crop.

The statistical difference was found in the effect of different planting time on *Rhizoctonia* canker on tubers. The maximum infection (21.11) percentage and PDI (0.49) of *Rhizoctonia* canker of potato was in the planting time 15th October and the minimum incidence (5.21) percentage and PDI (0.06) of *Rhizoctonia* canker of potato was in planting time 14th December (Table 15). Early planting increase the *Rhizoctonia* canker on tubers. For *Rhizoctonia* canker, suitable temperature is as below 10° C and above 24° C (Mulder and Turkensteen. 2005). Moreover, Development of these diseases is favored by soil temperatures between 16 to 23 °C, while soil temperatures above 25°C reduce the severity of canker reported by Anderson (1982).

4.2.13. Effect of different haulm pulling time on common scab and *Rhizoctonia* canker

There was no significant effect among the treatments of different haulm pulling time on case of common scab, but *Rhizoctonia* canker of potato (Table 15). The maximum % incidence (20.42) and PDI (30.35) on tubers was counted from the seeds of the haulm pulling at 82 DAP. The minimum % incidence (7.81) and PDI (0.11) on tubers was counted from the seeds of the haulm pulling at 68 DAP. Delay haulm pulling increase the *Rhizoctonia* canker incidence of tuber. These results are supported by Mulder *et al.*, (1992); Lootsma and Scholte, (1996) and Kumar *et al.*, (2017), where they opined that Green-crop-harvesting and immature-crop-harvesting, i.e. early haulm pulling often result in low levels of infection of *Rhizoctonia* canker.

4.2.14. Interaction effect of planting & haulm pulling time on common scab & *Rhizoctonia* canker

There were significant combined effects of planting and Haulm pulling time on common scab and *Rhizoctonia* canker of potato (Table 15). The highest incidence percentage (30.30) common scab was counted from 14th October planting with haulm pulling at 82 DAP and the lowest incidence percentage (6.41) was from 14th December planting with haulm pulling at 68 DAP. The maximum incidence (35.17) percentage and PDI (1.13) of *Rhizoctonia* canker of potato was c of planting time 14th October 89 DAP and the minimum incidence (5.80) percentage and PDI (0.06) of common scab of potato was the field of planting time 14th December with haulm pulling 89 DAP. The growth and development of plant in different planting time are presented in Plate 8 and 9(A.B.C&D).

Table 15. Effect of planting and haulm pulling times on tuber's common scab and *Rhizoctonia* canker of potato

Treatments	Common scab		<i>Rhizoctonia</i> canker	
	% Disease incidence	PDI (% Disease Index)	% Disease incidence	PDI (%Disease Index)
A. Planting time				
15 th October	25.16(4.97) a	42.55(6.41) a	21.11(4.46)a	0.49 a
04 th November	19.24(4.22) ab	32.98(5.24) ab	9.17(2.95) bc	0.13 b
24 th November	14.37(3.84) bc	22.36(4.63) bc	9.73(3.10) b	0.17 b
14 th December	10.06(3.15) c	13.03(3.46) c	5.21(2.29) c	0.06 b
LSD _{0.5}	0.865	1.5105	0.7643	0.3139
B. Haulm pulling at				
68 DAP	14.76	20.82	7.81(2.66) b	0.11 ab
75 DAP	15.88	27.88	7.96(2.83) b	0.09 b
82 DAP	20.42	30.35	13.56(3.62) a	0.25 a
89 DAP	17.77	31.86	15.88(3.69) a	0.41 a
LSD.5	NS	NS	0.7643	0.3139
Interaction A& B				
14 th Oct.+ 68 DAP	25.09 (4.93) a-c	36.59	16.04 (3.94) a-c	0.27 bc
14 th Oct. +75 DAP	26.77 (5.17) ab	52.98	9.61 (3.09) bc	0.12 bc
14 th Oct. + 82 DAP	30.30 (5.47) a	42.91	23.61 (4.83)ab	0.44 b
14 th Oct.+ 89 DAP	18.48 (4.33) a-d	37.71	35.17 (5.98) a	1.13 a
4 th Nov.+ 68DAP	12.71 (3.22) b-d	24.74	3.92 (1.74) c	0.04 c
4 th Nov. + 75DAP	12.04 (3.56) a-d	15.68	8.61 (3.01) bc	0.09 bc
4 th Nov. + 82DAP	27.87 (5.22) ab	43.25	11.34 (3.38) a-c	0.20 b
4 th Nov. + 89DAP	24.35 (4.88) a-c	48.23	12.80 (3.66) a-c	0.20 bc
24 th Nov.+ 68DAP	14.84 (3.94) a-d	14.84	5.47 (2.45) bc	0.05 c
24 th Nov. + 75DAP	15.35 (3.96) a-d	29.98	9.24 (3.07) bc	0.12 bc
24 th Nov. + 82DAP	11.28 (3.38) b-d	18.06	10.48 (3.29) a-c	0.25 b
24 th Nov. + 89DAP	16.01 (4.08) a-d	26.57	13.73 (3.61) a-c	0.27 bc
14 th Dec. + 68DAP	6.41 (2.66) d	7.12	5.80 (2.49) bc	0.06 c
14 th Dec. + 75DAP	9.34 (3.06) cd	12.89	4.40 (2.14) bc	0.05 c
14 th Dec. + 82DAP	12.23 (3.29) b-d	17.18	8.79 (2.99) bc	0.11 bc
14 th Dec. + 89 DAP	12.25 (3.57) a-d	14.92	1.84 (1.51) c	0.02 c
LSD _{0.05}	3.1574	NS	2.7898	0.5729
CV%	25.65	36.71	28.66	88.15

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. Figures in parenthesis indicate transformed (Square root/ Arcsine) value.

Experiment 3. **Effect of tuber size and gibberellic acid on quality potato seed Production**

The results of the study regarding the effect of different seed size and different concentration of gibberellic acid on disease free seed tuber production and growth characters, yield, yield related traits and diseases of potato have been presented in this chapter.



Plate 11. Sprouting of seed potato after application of GA₃

4.3.1.1. Effect seed potato size on number of sprouts

The effect of different seed size on sprouting was varied significantly. The sprouts of seed potato using different concentration of GA₃ is presented at Plate 11. The number of sprouts/tuber in the different size of seed tubers was ranged from 4.57 to 8.53. The highest number of sprouts per tuber (8.55) was recorded from S₄ and the lowest number of sprouts per tuber (4.57) was counted from S₁ (Table 16). The increase of seed size increases the branch number of sprouts /tuber. According to Hassani *et al.*, (2014), these differences can occur due to various physiological habits. The difference in seed size as well causes a difference in number of the sprout. So that the number of sprout increased whatever as well as seed tuber size increased. This indicates the importance of nutrient available storage in the seed tubers (Table 16). The result is also supported by the findings of Mayakaduwa *et al.* (2017), Michael *et al.* (2012) and Gulluoglu and Aroglu (2009); whose reported that the size of the seed tubers influenced emergence, had significant differences in mean percentage germination, and planting larger seeds positively affected all growth and yield components.

4.3.1.2. Effect of GA₃ on number of sprouts

The effect of different concentration of GA₃ on sprouting was varied significantly. The number of sprouts/tuber in the different GA₃ concentration was ranged from 6.60 to 6.91. The highest number of sprouts/ tuber (6.91) was recorded from G₀₀ and the lowest number of sprouts/ tuber (6.60) was counted from G₄₀ (Table 16).

4.3.1.3. Interaction effects of seed potato size and GA₃ on number of sprouts

The interaction effect of seed size and GA₃ on sprouts of seed potato is varied significantly (Table 16). The number of sprouts was ranged from 4.31 to 8.84. The maximum number of sprouts was produced from S₄G₀₀ which is statistically followed by S₄G₆₀. Largest mother tuber performed more sprouts/tuber. The minimum number of sprouts / tuber (4.31) was break out from S₁G₄₀ and smallest mother tuber produced comparatively minimum number of sprouts/tuber.

The largest seed tuber performed more number of sprouts per tuber due to present maximum eye point of potato. According to these differences can occur due to various physiological habits. This indicates the importance of nutrient available storage in the seed tubers. The result is also supported by the findings of Mayakaduwa *et al.* (2017), Michael *et al.* (2012), Hassani *et al.*, (2014), and Gulluoglu and Aroglu (2009); whose reported that the size of the seed tubers influenced emergence, had significant differences in mean percentage germination. The difference in seed size as well as causes a difference in number of the sprout. So that the number of sprout increased whatever as well as seed tuber size increased.

4.3.2.1. Effect seed potato size on branch number of sprout

There were significant effects of seed size on branch number of sprouts /tuber. The highest branch number of sprouts /tuber (23.05) was recorded from S₄ and the lowest branch number of sprouts /tuber (6.933) was counted from S₁ (Table 16). The increase of seed size increases the branch number of sprouts /tuber. This result is corroborated with Hassani *et al.*, (2014) and Mayakaduwa *et al.* (2017); where they opined that seed tuber size positively influence the sprouts per plant or stem per hill.

4.3.2.2. Effect of GA₃ on of branch number of sprout

There were significant effects of different concentration of GA₃ on sprout's branch number per tuber. The highest branch number of sprouts /tuber (17.90) was recorded from G₄₀ and the lowest branch number of sprouts /tuber (14.56) was counted from G₀₀ (Table 16). The sprout number per tuber is increased by applying GA₃ on mother seed tuber. This result is supported by Barani *et al.* (2013), where they reported that with increasing the concentration of gibberellic acid (GA₃) (0, 5, 10 mg/lit, respectively) more and more number of sprouts were observed. The result is also corroborated with the findings of Asalfew (2016), Mayakaduwa *et al.* (2017) and

Gulluoglu and Aroglu (2009); where they opined that GA₃ hastened early physiological maturity, increased average sprout number and sprout length of tubers.

4.3.2.3. Interaction effect of seed potato size and GA₃ on of branch Number of spouts

The maximum number of branches/tuber (26.2) was found in S₄G₂₀ which was followed by S₄G₄₀ (23.27) and S₃G₂₀ (22.07). These indicate that maximum number of spout's branches/tuber was produced from 20 ppm GA₃ and perform better in largest size tuber. The minimum number of spout's branches/tuber recorded from (7.13) with founds in S₁G₀₀ which was similar with S₁G₂₀, S₁G₄₀, S₁G₆₀ (Table 16). The larger surface area is more suitable to act of GA₃. The result is supported by the findings of Hassani *et al.* (2014), Virtanen *et al.*, (2013); where they stated that there is a positive influence of seed size and GA on sprouting of seed potato.

4.3.3.1. Effect seed size on weight of sprouts

The effect of different seed size on the weight of sprouts was varied significantly. The maximum the weight of 20 sprouts (10.58 mg) was recorded from S₃ and the lowest number of sprouts/ tuber (7.63 mg) was counted from S₁ (Table 16). The seed tuber size is positively influence the sprout weight per plant. The result is supported by the findings of Michael *et al.* (2012) and they stated that large and very large seed potato tubers exhibited greater overall resource use efficiency in all growth parameter of potato.

4.3.3.2. Effect of GA₃ on weight of sprouts

The effect of different concentration of GA₃ on the weight of sprouts was varied significantly. The maximum the weight of 20 sprouts (11.86 mg) was recorded from G₄₀ and the lowest number of sprouts/ tuber (5.300mg) was counted from G₀₀ (Table 16). The vigorous sprouting is influenced if GA₃ applied on mother seed tuber before sprouting. The result is corroborated with the findings of Asalfew (2016), Mayakaduwa *et al.* (2017), Barani *et al.* (2013) and Gulluoglu and Aroglu (2009); where they opined that GA₃ increase average sprout number, weight and sprout length of tubers.

4.3.3.3. Interaction effect of seed size and GA₃ on weight of sprouts

The weight of sprouts was varied significantly among the treatments (Table 16). The maximum weight was recorded from S₃G₄₀ which was followed by S₄G₄₀ and S₂G₄₀. The minimum weight of sprouts counted from S₁G₀₀. It indicate that 40 ppm is suitable for maximum healthy sprout production in tuber and GA₃ application can increase the weight of sprouts/tuber. The result is supported by the findings of Hassani *et al.* (2014), Virtanen *et al.*, (2013); where they stated that there is a positive influence of seed size and GA on sprouting of seed potato.

Table 16. Effect of seed size and GA₃ on sprouting of seed potato

Treatments	Sprouts/ tuber	Sprout branches /tuber	Weight of 20 sprouts (g)
A. Seed Size			
S ₁	4.57 d	6.93 d	7.63 c
S ₂	6.57 c	14.19 c	9.90 ab
S ₃	7.34 b	19.07 b	10.58 a
S ₄	8.53 a	23.05 a	9.43 b
LSD _{.05}	0.083	0.71	0.794
B. GA₃ Conc.			
G ₀₀	6.91 a	14.56 c	5.30 d
G ₂₀	6.60 b	16.13 b	11.06 b
G ₄₀	6.88 a	17.90 a	11.86 a
G ₆₀	6.62 b	14.66 c	9.33 c
LSD _{.05}	0.083	0.71	0.794
Interaction (A*B)			
S ₁ G ₀₀	4.81 i	7.13 g	3.43 i
S ₁ G ₂₀	4.62 j	6.63 g	9.47 efg
S ₁ G ₄₀	4.31 k	7.27 g	9.10 efg
S ₁ G ₆₀	4.52 j	6.70 g	8.53 g
S ₂ G ₀₀	6.50 g	13.10 f	5.43 h
S ₂ G ₂₀	6.34 gh	14.40 f	11.50 bcd
S ₂ G ₄₀	7.03 f	16.07 e	12.00 bc
S ₂ G ₆₀	6.31 h	13.20 f	10.67 cde
S ₃ G ₀₀	7.50 e	16.80 e	6.00 h
S ₃ G ₂₀	7.16 f	20.20 d	13.00 ab
S ₃ G ₄₀	7.84 d	22.07 bc	14.00 a
S ₃ G ₆₀	7.00 f	17.20 e	9.33 efg
S ₄ G ₀₀	8.84 a	21.20 cd	6.33 h
S ₄ G ₂₀	8.28 c	23.27 b	10.27 def
S ₄ G ₄₀	8.34 c	26.20 a	12.33 b
S ₄ G ₆₀	8.66 b	21.53 cd	8.77 fg
LSD _{0.05}	0.167	1.42	1.59
CV (%)	1.48	5.39	10.15

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.3.4.1. Effect of seed potato size on plant height

The different seed size was not affect significantly on plant height of potato at 30, 60 and 75 days after planting (DAP). But at 45 DAP, the plant height was varied significantly among the different seed sizes. The highest plant height was recorded from S₄, which was statistically similar with S₂ and S₃. The lowest plant height was recorded from S₁ (Table 17). Plant height was increased with increasing the size of seed tuber, due to large seed tubers had higher stored food materials, which enhance early emergence of crop and speed up vegetative growth of plant. These results were in close agreement with the findings of Mayakaduwa *et al.*, (2017), Sultana *et al.*, (2001) and Shingrup *et al.*, (2003) where they stated that tuber size influence the plant growth of potato.

4.3.4.2. Effect of GA₃ on plant height

GA₃ treatments manifested significant variation in respect of plant height at 60 and 75 days after planting, but was not significantly varied at 30 and 45 DAP. At 60 DAP, the highest plant height (66.63 cm) was observed at G₆₀ which was statistically followed by G₂₀, G₄₀ and G₀₀. At 75 DAP, the highest plant height (70.43 cm) was observed from G₆₀ which was statistically similar with G₄₀ and G₂₀. The lowest plant height (63.18 cm) was found in control (G₀₀) (table 17). The application of GA₃ increase the plant height, due to GA₃ enhance more cell elongation and cell division. This ultimately translates into higher plant height as reported by Prasad *et al.*, (2017) and Awati *et al.*, (2016) where they stated that GA accumulation enhance higher cell division and increase in plant height.

4.3.4.3. Interaction effect of seed size and GA₃ on plant height

Regarding the interaction effect of different seed size and different concentration of GA₃ on the plant height, the plant height at 30 DAP were varied significantly and ranges from 18.07 to 26.53 cm. The highest plant height was recorded from S₃G₀₀ which was similar with S₁G₆₀. The shortest plant height was recorded from S₃G₆₀ which was similar with S₁G₀₀. The plant height at 45 DAP were statistically different and ranges from 57.27 to 43.33 cm. The tallest plant height was recorded from S₃G₄₀ which was similar with S₃G₀₀. The shortest plant height was obtained from S₁G₀₀. At 60 DAP, the plant height were varied significantly among the different treatments and ranges from 55.60 to 69.53 cm. The maximum plant height was obtained from S₄G₆₀. The shortest plant height was obtained from S₁G₀₀. At 75 DAP, the plant height were varied significantly and ranges from 74.00 to 57.27 cm. The tallest plant height was obtained from the treatment of S₄G₆₀ which was similar with S₄G₂₀, S₃G₂₀, S₂G₆₀ and S₁G₆₀. The shortest plant height was obtained from S₁G₀₀ ((table 17). Application of GA₃ (20 to 60 ppm) in any size of mother seed tuber increase the plant height. These results are supported by the findings of Prasad *et al.*, (2017) and Awati *et al.*, (2016) where they stated that GA accumulation enhance higher cell division and increase in plant height.

Table 17. Effect of seed size and GA₃ on the plant height at different growth stage of potato

Treatments	Plant height (cm)			
	30DAP	45 DAP	60 DAP	75 DAP
A. Seed Size				
S ₁	22.23	46.70 b	61.77	67.13
S ₂	23.63	53.05 a	64.43	68.78
S ₃	22.18	52.78 a	63.10	67.87
S ₄	23.10	53.43 a	63.88	67.73
LSD _{.05}	NS	3.327	NS	NS
B.GA₃ Conc.				
G ₀₀	23.38	52.17	60.80 b	63.18 b
G ₂₀	23.05	52.42	63.77 ab	70.17 a
G ₄₀	21.43	50.17	61.98 b	66.73 ab
G ₆₀	23.28	51.22	66.63 a	71.43 a
LSD _{.05}	NS	NS	3.752	4.495
Interaction				
S ₁ G ₀₀	18.07 c	43.33 d	55.60 e	57.27 c
S ₁ G ₂₀	21.93 a-c	46.80 cd	57.73 de	68.93 ab
S ₁ G ₄₀	22.73 a-c	46.53 cd	66.13 a-d	68.73 ab
S ₁ G ₆₀	26.20 a	50.13 a-d	67.60 a-c	73.60 a
S ₂ G ₀₀	26.00 ab	57.13 ab	63.53 a-e	69.40 ab
S ₂ G ₂₀	22.80 a-c	53.47 a-c	63.87 a-e	68.33 ab
S ₂ G ₄₀	21.00 a-c	49.33 b-d	61.80 a-e	64.93 a-c
S ₂ G ₆₀	24.73 ab	52.27 a-c	68.53 ab	72.47 a
S ₃ G ₀₀	26.53 a	57.27 a	64.80 a-d	66.60 a-c
S ₃ G ₂₀	25.33 ab	56.13 ab	66.67 a-c	71.60 a
S ₃ G ₄₀	19.93 bc	51.60 a-c	60.07 b-e	67.60 ab
S ₃ G ₆₀	16.93 c	46.13 cd	60.87 a-e	65.67 a-c
S ₄ G ₀₀	22.93 a-c	50.93 a-c	59.27 c-e	59.47 bc
S ₄ G ₂₀	22.13 a-c	53.27 a-c	66.80 a-c	71.80 a
S ₄ G ₄₀	22.07 a-c	53.20 a-c	59.93 b-e	65.67 a-c
S ₄ G ₆₀	25.27 ab	56.33 ab	69.53 a	74.00 a
LSD _{.05}	6.54	6.65	7.50	8.99
CV (%)	13.81%	7.75	7.11	7.94

(Figures in a column having similar letter(s) do not differ significantly) Where, S₁=15 to 28 mm, S₂ = 28- 35 mm, S₃ = 35 - 45 mm and S₄ = 45- 55 mm and G₀₀ = 00 ppm GA₃, G₂₀ = 20 ppm GA₃, G₄₀ = 40 ppm GA₃ and G₆₀ = 60 ppm GA₃

4.3.5.1. Influence of seed size on stem number per hill

There was profound variation on stem number per hill was recorded among the different seed size of potato at 30, 45, 60 and 75 days after planting (Table 18). The highest stem number per hill were recorded from S₄ at 30 DAP (14.37), 45 DAP (15.32), 60 DAP (14.77) and 75 DAP (14.87). The lowest stem number per hill was recorded from S₁ at 30 DAP (3.40), 45 DAP (3.62), 60 DAP (3.54) and 75 DAP (3.62). The increased number of stems per hill obtained from the larger seedling tuber due to comparatively higher number of potential eyes per seed tuber were present in largest tuber, which lead to production of higher number of main stem per hill. The number of stem per hill increased significantly with the increase in seed size. These reports are supported by the results of Mayakaduwa *et al.*, (2017), Hassani *et al.*, (2014), Michael *et al.*, (2012), Gulluoglu and Aroglu (2009), and Sultana *et al.*, (2001). They reported that seed tuber size significantly influenced the growth, time to emergence, plant height, stem number per hill, leaf area coverage and yield of potato.

4.3.5.2. Influence of GA₃ on stem number per hill

The effect of different concentration of GA₃ on seed potato was significantly different in stem number per hill. The highest stem number per hill (10.13) at 30 days after planting (DAP) was observed in G₄₀ which was statistically similar with G₂₀ and G₆₀. The lowest number of stem per plant (6.18) was recorded from G₀₀. The similar results also recorded at 45, 60 and 75 DAP (Table 18). The mother seed tuber treated with GA₃ produced more number of stem per hill. The observed effect might be due to the activity of GA₃ in inducing cell elongation and cell division. These results corroborate the earlier findings of Prasad *et al.*, (2017), Awati *et al.*, (2016), Virtanen *et al.*, (2013) and Loretta and Mikitzel (1993) where gibberellic acid (GA) treatments significantly increased the number of sprouts per tuber and increased number of stem and tuber numbers per hill.

4.3.5.3. Interaction effect of seed size and GA₃ on stem number per hill

The interaction effect of different seed size and different concentration GA₃ on the stem number per hill at 30 DAP were statistically significant (Table 18). The maximum number of stem number per hill (18.00) was recorded from S₄G₆₀ which was followed by S₄G₂₀ or S₄G₄₀ (14.6/14.6) and S₃G₄₀ (12.93). The lowest stem number per hill (1.67) was found in S₁G₀₀.

At 45 DAP, the maximum stem number per hill (19.27) was found in S₄G₆₀, which was followed by S₄G₂₀ and S₃G₄₀. The minimum stem number per hill (1.73) was found in S₁G₀₀. At 60 DAP, the maximum stem number per hill (18.27) was recorded from S₄G₆₀ which was also followed by S₄G₂₀ (13.60). The minimum stem number per hill (1.73) was found in S₁G₀₀. The more or less similar results i.e. significantly variation were found in 75 DAP. The maximum stem number per hill (18.33) was recorded from S₄G₆₀ which was followed by S₄G₄₀ (14.00). The minimum stem number per hill (1.67) was found in S₁G₀₀. The lowest stem number per hill (1.67) was produced from S₁. But, 20/40 /60 ppm GA₃ application can increase the stem number per hill up to 4.00 stem per hill. Application of GA₃ in any size of mother seed tuber, increase the stem number per hill of potato. The result is supported by the findings of Prasad *et al.*, (2017), Awati *et al.*, (2016), Virtanen *et al.*, (2013) and Loretta and Mikitzel (1993) where they opined that the gibberellic acid (GA) treatments significantly increased the number of sprouts per tuber and increased number of stem and tuber numbers per hill.

4.3.6.1. The effect of seed size on LAC (%)

The effect of seed size on LAC (%) at 30 DAP was found to vary significantly from one another (Table 19). The highest LAC (32%) was found in S₄ which was followed by S₄ (30.17%). The lowest (9.92) was recorded from S₁. At 45 DAP, the maximum LAC (97.42%) was found in S₄ which was statistically similar with S₃ (95.50 %) and S₂ (92.83%). The lowest LAC (70.75 %) was recorded from S₁ at 45 DAP. The similar trend of LAC (%) was also recorded at 45 and 60 DAP from the different size of seed potato. Here increasing the seed size of potato increase the LAC % of the plant. May be due to the larger seed tuber contain maximum food storage for proper feeding of early emergence plant and produce maximum stems and leaves per plants at early stage. Moreover, the number of stem per hill increased significantly with the increase in seed size. These reports are supported by the results of Mayakaduwa *et al.*, (2017), Hassani *et al.*, (2014), Michael *et al.*, (2012), Gulluoglu and Aroglu (2009), and Sultana *et al.*, (2001). They reported that seed tuber size significantly influenced the growth, time to emergence, plant height, stem number per hill, leaf area coverage and yield of potato.

Table 18. Effect of seed size and GA₃ on the stem number per hill at different growth stage

Treatments	Stem number per hill			
	30 DAP	45 DAP	60 DAP	75 DAP
A. Seed Size				
S ₁	3.40 d	3.62 d	3.54 d	3.62 d
S ₂	7.40 c	7.54 c	7.40 c	7.35 c
S ₃	10.13 b	11.31 b	10.32 b	10.07 b
S ₄	14.37 a	15.32 a	14.77 a	14.87 a
LSD _{.05}	0.8312	1.045	0.8433	0.7623
B. GA₃ Conc.				
G ₀₀	6.18 b	6.49 b	6.18 b	6.02 b
G ₂₀	9.70 a	10.48 a	10.00 a	10.20 a
G ₄₀	10.13 a	10.44 a	9.93 a	9.68 a
G ₆₀	9.28 a	10.37 a	9.92 a	10.00 a
LSD _{.05}	0.8312	1.045	0.8433	0.7623
Interaction				
S ₁ G ₀₀	1.67 h	1.73 g	1.73 g	1.67 i
S ₁ G ₂₀	3.73 g	4.00 f	3.67 f	4.20 h
S ₁ G ₄₀	4.20 g	4.80 f	4.77 f	4.60 h
S ₁ G ₆₀	4.00 g	3.93 f	4.00 f	4.00 h
S ₂ G ₀₀	4.67 g	4.73 f	4.73 f	4.47 h
S ₂ G ₂₀	9.27 de	9.20 cde	8.80 de	9.00 def
S ₂ G ₄₀	8.80 de	8.83 de	8.80 de	8.60 efg
S ₂ G ₆₀	6.87 f	7.40 e	7.27 e	7.33 g
S ₃ G ₀₀	8.13 ef	9.03 de	7.80 e	7.73 fg
S ₃ G ₂₀	11.20 c	11.40 c	10.80 c	10.67 c
S ₃ G ₄₀	12.93 b	13.93 b	12.53 b	11.53 c
S ₃ G ₆₀	8.27 ef	10.87 cd	10.13 cd	10.33 cd
S ₄ G ₀₀	10.27 cd	10.47 cd	10.47 cd	10.20 cde
S ₄ G ₂₀	14.60 b	17.33 a	16.73 a	16.93 a
S ₄ G ₄₀	14.60 b	14.20 b	13.60 b	14.00 b
S ₄ G ₆₀	18.00 a	19.27 a	18.27 a	18.33 a
LSD _{.05}	1.66	2.09	1.69	1.53
CV (%)	11.29	13.27	11.23	10.19

[Figures in a column having similar letter (s) do not differ significantly] Where, S₁=15 to 28 mm, S₂ = 28- 35 mm, S₃ = 35 - 45 mm and S₄ = 45- 55 mm and G₀₀ = 00 ppm GA₃, G₂₀ = 20 ppm GA₃, G₄₀ = 40 ppm GA₃ and G₆₀ = 60 ppm GA₃

4.3.6.2. Effect of GA₃ on LAC (%)

The effect of GA₃ on LAC (%) at 30 DAP was found to vary significantly from one another (Table 19). The highest LAC (35%) was found in G₀₀ ppm GA₃ which was followed by G₄₀ ppm GA₃ (26.83%). The lowest (16.33) was recorded from G₆₀ ppm GA₃. Here increasing the concentration of GA₃ decreasing the LAC %. May be due to plants stems and leaves were thinner as compared to controls at seedling stage of plant (Table 3.4). This result is corroborated with the results of Awati, *et al.*, (2016). But there was no significant differences among the treatment at case of LAC at 45 DAP because the vegetative stage at 45 DAP was most vigorous and rapid. Significant Variations were also observed among the different concentration of GA₃ treated seed tubers in respect of LAC at 60 DAP. The highest LAC (95.00%) was observed in G₄₀. The lowest LAC was recorded from G₀₀. The similar results also recorded at 75 DAP. The application of GA₃ increase the LAC upto 60 DAP and give more LAC then control. GA accumulation in plants treated with growth enhancers which, resulted in higher cell division and increase in plant height. This results is supported by Alexopoulos *et al.*, (2006), where he explained as application of GA₃ significantly increased plant height and the total leaf area. The increase in total leaf area resulted from an increase in average leaf size. The result is corroborated with the findings of Prasad *et al.* (2013), where they stated that there is a linear increase of growth parameter with increasing level of GA₃ (20-80 ppm) and NAA (25-100 ppm).

4.3.6.3. Interaction effect of seed size and GA₃ on LAC (%)

The interaction effect of different seed size and different conc. of GA₃ on LAC at 30, 45, 60 and 75 DAP was statistically significant (Table 19). At initial stage, 30 DAP, the highest LAC 45% found from S₃G₀₀, which was statistically similar with S₄G₀₀ (40%). The lowest LAC (0.67%) was observed from S₁G₆₀. At seedling stage, without application of GA₃ performed better LAC than without application of GA₃, may be due to using GA₃ in seed tuber enhanced seed to produce more sprouts/plant than the growth of canopy. At 45 DAP, the highest LAC (100%) was recorded from S₄G₆₀ which was statistically similar with all seed sizes with all GA₃ concentration except S₁G₀₀, S₁G₂₀, S₁G₄₀, S₁G₆₀. The lowest LAC (64.33%) was recorded from S₁G₆₀. The similar effects were found in the interaction effect of seed size and GA₃ on LAC at 60 DAP. The highest LAC (98.33%) was recorded from S₃G₄₀. The lowest LAC (73.33%) was in S₁G₀₀. At 75 DAP, the LAC was also statistically different from one another. The maximum LAC (94.33) was in S₄G₄₀. The lowest LAC (78.33) was recorded from S₁G₆₀. These may be due to application of GA₃ on seed tuber, influence cell division and elongation and ultimately prolong its vegetative growth period. The result is corroborated with the findings of El-hamady (2017), where he stated that GA₃ influence the dormancy of shoot and other part of plant. But the result is conflict with the findings of Asalfew (2016), where he stated that Haulm applications of GA₃ at 750 and 1000 ppm hastened early physiological maturity.

Table 19. Effect of seed size and GA₃ on leaf area coverage at different stage of potato

Treatments	LAC 30 DAP	LAC 45 DAP	LAC 60 DAP	LAC 75 DAP
A. Seed Size				
S ₁	9.92 (1.59) c	70.75 (4.67) b	81.75 (9.03) b	82.83 (9.09) b
S ₂	26.92 (2.86) b	92.83 (5.34) a	94.58 (9.72) a	91.17 (9.54) a
S ₃	30.17 (2.96) ab	95.50 (5.41) a	96.25 (9.81) a	88.42 (9.40) a
S ₄	32.00 (3.10) a	97.42 (5.47) a	95.71 (9.78) a	88.75 (9.41) a
LSD _{.05}	0.1537	0.2142	0.2373	0.3041
B. GA₃ Conc.				
G ₀₀	35.00 (3.22) a	88.58 (5.23) a	88.50 (9.39) b	83.33 (9.12) b
G ₂₀	20.83 (2.43) c	90.33 (5.24) a	94.00 (9.69) a	89.25 (9.44) ab
G ₄₀	26.83 (2.84) b	92.17 (5.32) a	95.00 (9.74) a	92.17 (9.60) a
G ₆₀	16.33 (2.01) d	85.42 (5.09) a	90.83 (9.52) ab	86.42 (9.29) ab
LSD _{.05}	0.1537	0.2142	0.2373	0.3041
Interaction				
S ₁ G ₀₀	17.67 (2.32) ef	70.33 (4.75) c-e	73.33 (8.56) d	79.67 (8.92) b-d
S ₁ G ₂₀	7.33(1.47) h	68.67 (4.55) de	84.00 (9.15) bc	82.00 (9.04) a-d
S ₁ G ₄₀	14.00 (2.07) fg	79.67 (4.95) b-d	88.33 (9.40)a-c	91.33 (9.55) a-c
S ₁ G ₆₀	0.67 (0.497) i	64.33 (4.43) e	81.33 (9.01) cd	78.33 (8.84) d
S ₂ G ₀₀	37.33 (3.38) bc	93.67 (5.36) ab	94.33 (9.71) a	88.67 (9.41)a-d
S ₂ G ₂₀	22.33 (2.61) e	95.67 (5.41) ab	97.00 (9.85) a	91.67 (9.56) a-c
S ₂ G ₄₀	28.33 (3.01) d	94.00 (5.41) ab	96.00 (9.80) a	92.33 (9.61) ab
S ₂ G ₆₀	19.67 (2.45) e	88.00 (5.19) a-c	91.00 (9.54) a-c	92.00 (9.59) a-c
S ₃ G ₀₀	45.00 (3.70) a	96.33 (5.43) ab	95.33 (9.76) a	86.00 (9.27) a-d
S ₃ G ₂₀	33.67 (3.19) d	99.00 (5.51) a	97.67 (9.88) a	92.33 (9.61) ab
S ₃ G ₄₀	29.00 (2.99) d	97.33 (5.46) a	98.33 (9.92) a	90.67 (9.52) a-d
S ₃ G ₆₀	13.00 (1.99) g	89.33 (5.21) a-c	93.67 (9.67) ab	84.67 (9.19) a-d
S ₄ G ₀₀	40.00 (3.50) ab	94.00 (5.36) ab	91.00 (9.53) a-c	79.00 (8.88) cd
S ₄ G ₂₀	20.00 (2.47) e	98.00 (5.49) a	97.33 (9.67) a	91.00 (9.54) a-d
S ₄ G ₄₀	36.00 (3.31) bcd	97.67 (5.47) a	97.33 (9.87) a	94.33 (9.71) a
S ₄ G ₆₀	32.00 (3.17) cd	100.0 (5.54) a	97.33 (9.87) a	90.67 (9.52) a-d
LSD _{.05}	0.31	0.43	0.48	0.62
CV (%)	7.06	4.93	2.96	3.89

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.3.7.1. Effect of seed potato size on tuber number

The mother seed tuber size affected tuber number per plant was varied significantly. The maximum number (1.82) of ≤ 10 mm tuber per plant was counted from S₄ and the minimum (0.93) was counted from S₂ (Table 20). The maximum number (11.48) of 10-28 mm tuber per plant was counted from S₄ and the minimum (5.09) one counted from S₁. The highest number (6.77) of “A” grade (28 to 40 mm) tuber per plant were found from S₄, which was statistically similar with S₃ (6.70). The lowest number (3.87) of “A” grade tuber per plant was counted from S₁.

In case of “B” grade seed tuber per plant, the highest number (3.93) was recorded from S₃ and the lowest number (2.20) of “B” grade seed tuber per plant was counted from S₁. The highest total tuber number per plant (23.24) was recorded from S₄ which was statistically similar with S₃ and followed by S₂. The lowest number of tuber per plant (12.43) was produced from small of S₁ (Table 20).

The results of the experiments showed that, the number of tuber decreased with decreasing seed tubers size. Bigger seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites (Michael *et al.*, 2012). Moreover, seed tuber size significantly affected the tuber yield. Gulluoglu and Arioglu (2009) reported that tuber yields per hectare consistently increased with increasing seed size. Moreover, Mayakaduwa *et al.* (2017) was found that the emergence, growth and yield decreased with decreasing size of seed tuber planted.

4.3.7.2. Effect of GA₃ on tuber number

The tuber number per plant affected by different concentration of GA₃ application on seed tuber was varied significantly (Table-20). The maximum number (1.86) of ≤ 10 mm tuber per plant was recorded from G₆₀ and the minimum (0.50) number of ≤ 10 mm tuber per plant was recorded from G₀₀. The highest number (11.14) of 10-28 mm tuber per plant was recorded from G₆₀ which was similar with G₄₀ or G₂₀. The lowest (3.74) number of 10-28 mm tuber per plant was recorded from G₀₀. The highest number (6.46) of “A” grade (28 - 40 mm) seed tuber was observed from G₆₀ which was statistically similar with G₄₀ and G₂₀. The minimum (3.99) number of “A” Grade tuber was recorded from G₀₀. The highest number of “B” Grade (40 – 55 mm) seed (3.91) was found from G₀₀ and lowest one recorded from G₆₀. Similarly, the highest number of over size (> 55 mm) tuber (0.28) was found from G₀₀ and the lowest one recorded from G₂₀. The maximum total tuber number per plant (22.28) was also recorded from G₆₀ which was similar with G₄₀ or G₂₀. The minimum number of tuber per plant (12.33) was recorded from G₀₀. The number of “B” grade tuber is gradually decreased by increasing GA₃ concentration. These may be due to application of GA₃ increase sprout number / tuber or stem number / plant which increase more number of tuber / plant. These more number of tubers was consumed similar nutrients comparison with G₀₀ and the tubers become smaller. Similar findings have also been reported by Akbari *et al.*, (2013), Loretta and Mikitzel (1993) and Caldiz (1996), they reported that the production of seed tubers increased by using gibberellic acid hormone.

4.3.7.3. Interaction effect of seed potato size and GA₃ on tuber number

The number of tuber per plant was significantly influenced by the combined effect of both seed size and GA₃. There was a significant effect of the interaction of seed size and GA₃ concentration on production of ≤ 10 mm, 10 to 28 mm, 28 to 40 mm, 40 to 55 mm and ≥ 55 mm tuber number per plant (Table 20).

The maximum number of ≤ 10 mm tuber per plant (3.13) was recorded from S₄G₆₀ and the lowest number of tuber per plant (0.33) was counted from S₂G₀₀. The largest number of 10 to 28 mm tuber per plant (14.50) was recorded from the treatment of S₄G₆₀ and the lowest number (0.90) tuber per plant was recorded from S₁G₀₀. Among the treatment the maximum number of “A” grade tuber (28 - 40 mm) per plant (7.5) was recorded from S₄G₄₀ which was statistically similar with S₄G₄₀, S₃G₄₀ and S₃G₆₀. The minimum number (2.17) of “A” grade tuber was counted from the treatment of S₁G₀₀. The highest number of “B” grade tubers (40 - 55 mm) per plant (4.77) was produced from the treatment of S₄G₀₀, which was followed by S₄G₂₀, S₄G₀₀, S₂G₄₀, S₄G₆₀, S₃G₄₀ and S₃G₆₀. The lowest number of “B” grade seed tubers per plant (2.00) were collected from the treatment of S₁G₄₀. The maximum number of over size tuber was counted from S₄G₀₀. Application of GA₃ in seed potato increase the total tuber number per plant. The results are supported by Daniel O. Caldiz (1996), where he stated the use of these PGRs under both field and glasshouse conditions in cvs. Mailen and Spunta resulted in increased tuber number in the seed fraction. GA increase the tuber number of potato. The result is also corroborated with the findings of Virtanen *et al.* (2013), El-hamady (2017), Loretta and Mikitzel (1993) and Asalfew (2016) Stated that Gibberellic acid increase the stem number, tuber number, tuber yield per plant and also increase the quality of potato.

The interaction effect of seed size and GA₃ on the total tuber number per plant was varied significantly. The highest number of tuber per plant (27.73) was recorded from S₄G₆₀ which was similar with S₄G₄₀ (25.33), S₃G₄₀ (25.47). The lowest total tuber number per plant (6.30) recorded from S₁G₀₀. The maximization of tuber number per plant was due to larger seed size and GA₃ application in mother seed tuber (Table 20). The results are in agreement with Loretta and Mikitzel (1993) where they reported that GAs treatments increased stem and tuber numbers per hill and shifted tuber size profile toward the production of more seed-sized (up to 226 g) tubers and fewer large (greater than 340 g) tubers. The results are also supported by Daniel O. Caldiz (1996), Virtanen *et al.* (2013), El-hamady. (2017), Loretta and Mikitzel (1993) and Asalfew (2016) stated that Gibberellic acid increase the stem number, tuber number, tuber yield per plant and also increase the quality of potato.

Table 20. Effect of seed size and GA₃ on the tuber number per plant

Treatments	Tuber number per plant					Total
	<10mm	10-28 mm	28-40 mm	40-55 mm	>55 mm	
A. Seed Size						
S ₁	1.12 b	5.07 d	3.87 c	2.2 c	0.23	12.43 c
S ₂	0.93 b	8.9 c	5.55 b	3.39 ab	0.13	18.80 b
S ₃	1.12 b	10.18 b	6.7 a	3.93 a	0.13	22.00 a
S ₄	10.82 a	11.48 a	6.77 a	3.07 b	0.13	23.24 a
LSD _{.05}	0.45	1.00	0.64	0.71	0.10	2.07
B. GA ₃ Conc.						
G ₀₀	0.5 c	3.74 b	3.99 b	3.91 a	0.28 a	12.33 b
G ₂₀	1.2 b	10.5 a	6.15 a	2.96 b	0.09 b	20.84 a
G ₄₀	1.44 ab	10.24 a	6.28 a	2.97 b	0.13 b	21.03 a
G ₆₀	1.86 a	11.14 a	6.46 a	2.76 b	0.12 b	22.28 a
LSD _{.05}	0.45	1.00	0.64	0.71	0.10	2.07
Interaction						
S ₁ G ₀₀	0.67 b	0.9 e	2.17 e	2.43 ab	0.23 ab	6.30 h
S ₁ G ₂₀	1.2 b	5.73 d	3.83 de	2.2 b	0.17 ab	13.07 fg
S ₁ G ₄₀	1.1 b	6.9 cd	5.2 b-d	2 b	0.17 ab	15.33 f
S ₁ G ₆₀	1.5 ab	6.73 cd	4.27 d	2.17 b	0.33 ab	15.00 fg
S ₂ G ₀₀	0.33 b	3.6 de	3.77 de	3.9 ab	0.23 ab	11.70 g
S ₂ G ₂₀	1.03 b	10.1 bc	5 cd	3.53 ab	0.13 ab	19.67 de
S ₂ G ₄₀	1.13 b	10.97 ab	6.7 a-c	3.5 ab	0.07 ab	22.33 b-d
S ₂ G ₆₀	1.23 b	10.93 ab	6.73 a-c	2.63 ab	0.07 ab	21.50 cd
S ₃ G ₀₀	0.63 b	4.5 de	5.03 cd	4.53 ab	0.27 ab	14.90 fg
S ₃ G ₂₀	0.97 b	11.57 ab	6.57 a-c	3.53 ab	0.17 ab	22.77 b-d
S ₃ G ₄₀	1.33 b	12.23 ab	7.87 a	4.03 ab	0.03 ab	25.47 ab
S ₃ G ₆₀	1.57 ab	12.4 ab	7.33 a	3.63 ab	0.03 ab	24.87 a-c
S ₄ G ₀₀	0.37 b	5.97 d	5 cd	4.77 a	0.37 a	16.40 ef
S ₄ G ₂₀	1.83 ab	12.07 ab	7.23 ab	2.37 ab	0.00 b	23.50 bc
S ₄ G ₄₀	1.97 ab	13.4 ab	7.33 a	2.53 ab	0.13 ab	25.33 ab
S ₄ G ₆₀	3.13 a	14.5 a	7.5 a	2.6 ab	0.03 ab	27.73 a
LSD _{.05}	1.66	3.87	2.05	2.56	0.35	3.43
CV (%)	42.99	13.47	13.43	26.91	77.99	6.48

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.3.8.1. Effect of seed potato size on tuber weight of potato

The effect of different size of mother seed tuber on tuber weight per plant was differ significantly. The weight of ≤ 10 mm tubers per plant were varied significantly. The maximum (1.47 g) and the minimum (0.66 g) weight of ≤ 10 mm tubers were recorded from S₃ and S₁, respectively (Table 21). The different size tuber per plant was also statistically significant among different mother seed tuber size. The highest weight (135.98 g) of 10 - 28 mm tuber was counted from S₄ which was statistically followed by S₃ or S₂. The lowest weight (44.38 g) of 10 - 28 mm tuber was recorded from S₁. The maximum weight of “A” grade (28-40 mm) seed tuber per plant (233.32 g) were recorded from S₃ which was statistically similar with S₄. The minimum weight of “A” grade tuber per plant (131.43 g) were observed in S₁.

The significant difference among the different size of mother seed tuber was also found in case of “B” Grade (40 – 55 mm) tuber per plant. The maximum weight (279.04 g) of “B” grade tuber per plant was pointed out from S₃ which was statistically similar with S₄. The minimum weight of “B” grade tuber per plant (196.93 g) was counted from S₁. The ≥ 55 mm tubers per plant was differ statistically. The tuber size influence the tuber yield and quality of seed potato. The result is supported by the findings of Khalafalla (2001), Upadhya and Cabello (2001), Michael *et al.* (2012) and Sultana *et al.* (2001) where they stated that the seed tuber size positively influenced all growth and yield component of potato.

4.3.8.2. Effect of GA₃ on the tuber weight of potato

The tuber weight per plant was varied significantly among the different concentration of GA₃ application on mother seed tuber. The maximum weight of ≤ 10 mm tuber per plant (1.56 g) was recorded from G₆₀ and the lowest weight of ≤ 10 mm tuber per plant (0.35 g) was counted from G₀₀. The highest weight of 10 to 28 mm tuber per plant (120.88 g) was recorded from G₆₀ which was statistically similar with G₄₀ or G₂₀. The lowest weight of 10 to 28 mm tuber per plant (28.49 g) was counted from G₀₀. The highest weight of “A” grade tuber per plant (233.47 g) was recorded from G₆₀ which was statistically similar with G₂₀ or G₄₀. The lowest weight of “A” grade tuber per plant (131.07 g) was counted from G₀₀. The maximum weight of “B” grade tuber per plant (310.07 g) was recorded from G₀₀ which was statistically followed by G₂₀ or G₄₀. The lowest weight of “B” grade tuber per plant (213.82 g) was counted from G₆₀. The maximum weight of ≥ 55 mm tuber per plant (47.58 g) was recorded from G₀₀ and the lowest weight (19.15 g) was counted from G₆₀. The seed treated with GA₃ increase tuber number per plant per unit area (Table 21). The more tuber per plant need more foods per unit area which was not provided. So the produced tubers were in the size of quality seed tuber. So it can be stated that GA₃ application in mother seed tuber can increase tuber yield and tuber quality of potato. The result is supported by the findings of Asalfew (2016), Barani *et. al.*, (2013), where they stated that using GA₃ in seed tuber increase the tuber yield.

4.3.8.3. Interaction effect of seed potato size and GA₃ on the tuber weight of potato

The interaction effect of different size of mother seed tuber and different GA₃ concentration on tuber weight per plant were varied significantly from one another (Table 21). The weight of ≤ 10 mm tuber weight per plant were ranged from 2.27 g to 0.17 g where the highest and lowest tuber weight per plant were in found in S₃G₆₀ and S₁G₀₀, respectively. The weight of 10 to 28 mm tuber weight per plant were ranged from 197.8 g to 6.5 g where the highest and the lowest tuber weight were recorded from S₄G₄₀ and S₁G₀₀, respectively. The maximum weight of “A” Grade (28 to 40 mm) tuber per plant (282.9 g) was counted from S₃G₆₀ which was similar with S₄G₆₀, S₄G₂₀ and S₃G₆₀. The minimum weight of “A” grade tuber per plant (79.60 g) was found in S₁G₀₀. The significant differences was not found in “B” grade and over size tuber. The maximum weight of “B” grade (40 to 55 mm) tubers per plant (344.6 g) were recorded from S₃G₀₀ and the lowest weight (183.3 g) f “B” grade seed per plant recorded from S₁G₂₀. The highest ≥ 55 mm tuber weight per plant (53.1 g) were in S₄G₀₀ and the lowest weight was 0.00 g from S₄G₂₀ (Table 3.6). These indicated that GA₃ application decrease the weight of large tuber size and increase the “A” and “B” grade and below size tuber per plant. These results are supported by the findings of Asalfew, (2016) and Barani *et al.*, (2013), where they stated that seed tuber treated with GA₃ increase the seed tuber yield.

4.3.9.1. Influence of seed potato size on plant population

The effect of different tuber size on plant population number per m² was varied significantly. The maximum number (6.63) of plants per plot was established in S₂ which was similar with S₃ and S₄. The minimum number (6.43) of plant per plot was recorded from S₁ (Table 22). Bigger mother seed tubers were germinate more successfully than smaller seed tuber. These results were in close agreement with the findings of Mayakaduwa *et al.*, (2017) and Sultana *et al.*, (2001), where they stated that the size of mother seed tuber influence the germination percentage of potato.

4.3.9.2. Effect of GA₃ on plant population

Regarding the effect of different concentration of gibberellic acid (GA₃) on population/m², it had been obtained that the maximum number (6.67) of plants per m² was counted from G₂₀ which was statistically identical with G₆₀ (Table 22). The minimum number (6.43) of plant/plot was recorded from G₀₀. This result indicate that application of GA₃ in appropriate concentration can increase the germination percentage of seed tuber in the field. Similar result was also reported by Barani *et al.* (2013), Virtanen *et al.*, (2013), Asalfew. (2016), El-hamady. 2017 and Prasad *et al.*, (2017), where they stated that seed treated with GA₃ increase the germination percentage, number of sprouts and increase general performance and early emergence of shoot.

Table 21: Effect of seed size and GA₃ on the tuber weight per plant of potato

Treatments	Tuber weight per plant (g)				
	≤10mm	10-28mm	28-40mm	40-55mm	≥55mm
A. Seed Size					
S ₁	0.66 c	44.38 c	131.43 c	196.93 b	34.56
S ₂	1.02 b	80.23 b	195.65 b	266.02 a	26.14
S ₃	1.47 a	96.83 b	233.32 a	279.04 a	22.84
S ₄	1.42 a	135.98 a	231.43 a	246.65 a	19.77
LSD _{.05}	0.3331	23.1158	21.8925	45.5193	16.225
B. GA₃ Conc.					
G ₀₀	0.35 b	28.49 b	131.07 c	310.07 a	47.58 a
G ₂₀	1.34 a	98.63 a	221.16 ab	227.67 b	16.96 b
G ₄₀	1.32 a	109.43 a	206.12 b	237.07 b	19.62 b
G ₆₀	1.56 a	120.88 a	233.47 a	213.82 b	19.15 b
LSD _{.05}	0.3331	23.1158	21.8925	45.5193	16.225
Interaction A x B					
S ₁ G ₀₀	0.17 f	6.5 f	79.6 f	232.5	40.3
S ₁ G ₂₀	0.77 c-f	52.6 c-f	134.4 ef	183.3	31.4
S ₁ G ₄₀	0.57 d-f	61.5 c-f	164.7 c-e	186.6	23.7
S ₁ G ₆₀	1.13 b-f	57.0 c-f	147.1 d-f	185.3	42.9
S ₂ G ₀₀	0.23 f	32.4 ef	133.1 ef	326.4	43.4
S ₂ G ₂₀	1.57 a-d	89.2 c-f	182.7 b-e	264.0	26.0
S ₂ G ₄₀	1.43 a-e	94.3 c-e	233.3 a-c	243.4	18.5
S ₂ G ₆₀	0.83 c-f	105.0 b-e	233.6 a-c	230.2	16.7
S ₃ G ₀₀	0.6 d-f	37.7 d-f	164.1 c-e	344.6	53.5
S ₃ G ₂₀	1.13 b-f	106.0 b-e	236.8 a-c	271.5	21.8
S ₃ G ₄₀	1.87 a-c	120.0 a-d	249.5 ab	272.8	7.5
S ₃ G ₆₀	2.27 a	123.6 a-c	282.9 a	227.4	8.6
S ₄ G ₀₀	0.40 ef	37.4 d-f	147.6 d-f	336.7	53.1
S ₄ G ₂₀	1.73 a-c	126.1 a-c	282.6 a	213.3	0.0
S ₄ G ₄₀	1.57 a-d	182.7 ab	225.2 a-d	224.2	17.5
S ₄ G ₆₀	2.00 ab	197.8 a	270.4 a	212.4	8.4
LSD _{.05}	1.12	84.09	80.92	167.72	58.29
CV (%)	35	31.03	13.26	22.09	75.35

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Figures in parenthesis indicate transformed values.

4.3.9.3. Interaction effect of seed size and GA₃ on plant population

The effects of different seed sizes in combination with different concentration of GA₃ on population/m² were statistically significant. The maximum plant population/m² (6.67) was counted from S₁G₂₀ which was similar with S₁G₄₀, S₂G₂₀, S₂G₄₀, S₃G₂₀, S₃G₄₀, S₄G₂₀. The minimum number (6.11) of population/m² was recorded from control S₁G₀₀ (Table 22).

This result indicate that application of GA₃ in any size of mother seed tuber increase the germination percentage of seed tuber in the field. Similar result was also reported by Barani *et al.*, (2013), Virtanen *et al.*, (2013), Asalfew, (2016), El-hamady. 2017 and Prasad *et al.*, (2017), where they stated that seed treated with GA₃ increase the germination percentage, increase the number of sprouts, increase general performance and early emergence of shoot.

4.3.10.1. Effect of different tuber size on canopy weight

The effect of different tuber size on canopy weight per plant was varied significantly. The maximum canopy weight per plant (0.89 g) was recorded in S₄ and the minimum canopy weight per plant (0.23 g) was in S₁ (Table 22). The large seed tuber produced more vegetative growth of canopy. These results were consistent with the findings Mayakaduwa *et al.*, (2017) and Michael *et al.*, (2012), where they stated that large size seed potato tubers are preserved relatively larger food reserves, which help to produced large plants and established faster and produced vigorous stems, which increases the efficiency of biomass partitioning to the tubers.

4.3.10.2. Effect of GA₃ on canopy weight

The effect of different concentration of gibberellic acid (GA₃) on canopy weight per plant was varied significantly. The maximum canopy weight per plant (0.63 kg) was recorded from G₆₀ which was similar with G₄₀ and G₂₀ (Table 22). The minimum canopy weight/plant (0.38 kg) was recorded from G₀₀. The GA₃ treated seed potato performed comparatively larger leaf area coverage and ultimately increase the canopy weight of potato plant. Similar result was also reported by Prasad *et al.*, (2017) and El-hamady. 2017, Awati *et al.* (2016), Alexopoulos *et al.* (2006) and Loretta and Mikitzel (1993) ; where they stated that increasing rates of concentration of GA₃ markedly increased plant height, chlorophyll content and foliage fresh weight per plant.

4.3.10.3. Interaction effect of seed potato size and GA₃ on canopy weight

The combined effects of different seed sizes in combination with different concentration of GA₃ on canopy weight/plant were varied significantly. The maximum canopy weight/plant (1.15 kg) was from S₄G₆₀. The minimum canopy weight/plant (0.10 kg) was recorded from

S₁G₀₀ (Table 22). The GA₃ increase the vegetative growth and increase seed size create field of sprouting and branching.

The GA₃ treated seed potato performed comparatively larger leaf area coverage and ultimately increase the canopy weight of potato plant. The seed size and GA₃ concentration upto 60 ppm has a positive effect on canopy coverage or canopy weight. Similar result was also reported by Prasad *et al.*, (2017) and Awati *et al.*, (2016), Alexopoulos *et al.*, (2006) and Loretta and Mikitzel (1993) ; where they stated that increasing rates of concentration of GA₃ markedly increased plant height, chlorophyll content and foliage fresh weight per plant. The result is also corroborated with the findings of El-hamady. (2017). Where he stated that the increasing rates of concentration of GA₃ from 0 ppm GA₃ to 30 ppm GA₃ markedly increased plant height, chlorophyll content, foliage fresh and dry weight g/plant.

4.3.11.1. Effect of seed potato size on tuber weight

Effect of seed size on the total tuber weight per plants was significant. The height tuber weight (635.21 g) per plants was recorded from S₄ which was statistically similar with S₃. The minimum tuber weight per plants (407.88 g) were counted from S₁ (Table 22).

The tuber weight per plant was increased with increasing mother seed tuber size. This result are also supported by the result of Khalafalla, 2001; BongKyoony *et al.*, 2001; Shingrup *et al.*, 2003; Verma *et al.*, 2007 who reported that tuber number per hill increased with increasing tuber weight till 55 g seed tuber.

4.3.11.2. Influence of GA₃ on total tuber weight

Effect of gibberellic acid (GA₃) on the total tuber weight per plants was varied significantly. The highest tuber weight (588.81 g) per plants was recorded from G₆₀ which was statistically similar with G₄₀ and G₂₀. The minimum tuber weight per plants (517.49 g) was counted from G₀₀ (Table 22). The use of gibberellic acid in seed tuber increase the total tuber weight per plant. These result is similar with the result of Javanmardi and Rasuli (2017), where they stated that treatment with 20 mg·L⁻¹ GA₃ and 100 mg·L⁻¹ zinc sulfate increase total tuber weight per plant. These result is also supported by the finding of Akbari *et al.*, (2013) and El-hamady. (2017), where they stated that GA₃ hormone influence the weight of potato per plant.

4.3.11.3. Interaction effect of seed size and GA₃ on tuber weight

Significant variation was observed among the combinations between different seed sizes and different concentration of GA₃ on the tuber weight per plants. The height tuber weight (691 g)

per plants was recorded from the S₄G₆₀ which was statistically similar with S₄G₄₀, S₄G₂₀, S₃G₂₀, S₃G₄₀, S₃G₆₀. The minimum tuber weight per plants (359 g) were counted from S₁G₀₀ (Table 22). The different size of seed tubers treated with GA₃ increase the tuber weight per plant. These result is corroborated with the findings of Javanmardi and Rasuli (2017), where they stated that a 38% increase in total tuber yield resulted from treatment with 20 mgL⁻¹ GA₃ and 100 mgL⁻¹ zinc sulfate. The similar result is also reported by Akbari *et al.*, (2013) and El-hamady (2017), where they stated that GA₃ hormone influence the weight of potato per plant.

4.3.12.1. Influence of seed potato size on yield of potato

Effect of seed size on yield was also varied significantly. The highest yield (40.46 ton/ha) was recorded from S₃ which was statistically similar with S₄ (40.32 ton/ha). The minimum yield (24.71 ton/ha) was counted from S₁ (Table 22). Increasing mother seed tuber size increase the yield of potato. Similar result was also reported Khalafalla, 2001; BongKyoony *et al.*, 2001; Shingrup *et al.*, 2003 and Verma *et al.*, 2007 whose reported that increasing the seed tuber weight till 55 g seed tuber increase the tuber number hill⁻¹.

4.3.12.2. Effect of GA₃ on yield of potato

The highest yield (37.32 ton/ha) was recorded from the G₆₀ which was statistically similar with G₂₀ and G₄₀. The minimum tuber yield (32.12 ton/ha) was recorded from G₆₀ (table 22). The application of GA₃ at mother seed tuber increase the yield of potato. These result is supported by the result of Javanmardi and Rasuli (2017), where they stated that 38% tuber yield was increased resulted from treatment with 20 mgL⁻¹ GA₃ with 100 mgL⁻¹ zinc sulfate. These result is also supported by the finding of Akbari *et al.* (2013), Javanmardi and Rasuli (2017) and El-hamady. (2017), where they stated that GA₃ hormone influence the yield of potato.

4.3.12.3. Interaction effect of seed potato size and GA₃ on yield of potato

The effect of different seed size and different concentration of GA₃ on yield was significant. The height yield (42.67 ton/ha) was recorded from S₄G₆₀. The minimum tuber weight per plants (18.47 ton/ha) was counted from S₁G₀₀. (Table 22). Any size of seed tuber treated with GA₃ increase the yield of potato. These result is corroborated with the findings of Javanmardi and Rasuli (2017), where they stated that a 38% increase in total tuber yield resulted from treatment with 20 mg·L⁻¹ GA₃ and 100 mg·L⁻¹ zinc sulfate. The similar result is also reported by Akbari *et al.*, (2013) and El-hamady (2017), where they stated that GA₃ hormone influence the weight of potato per plant.

Table 22. Yield and yield component of potato affected by seed size and GA₃

Treatments	population /m²	Canopy wt/ plant (Kg)	Total tuber wt/plant (g)	Yield (ton/ha)
A.. Seed Size				
S ₁	6.43 b	0.23 d	407.88 c	24.71 c
S ₂	6.63 a	0.46 c	568.97 b	36.63 b
S ₃	6.60 a	0.63 b	633.43 a	40.46 a
S ₄	6.57 ab	0.89 a	635.21 a	40.32 a
LSD _{.05}	0.144	0.05273	25.0024	1.6453
B. GA₃ Conc.				
G ₀₀	6.43 b	0.38 b	517.49 b	32.12 b
G ₂₀	6.67 a	0.60 a	565.72 a	36.26 a
G ₄₀	6.67 a	0.61 a	573.48 a	36.42 a
G ₆₀	6.46 b	0.63 a	588.81 a	37.32 a
LSD _{.05}	0.1444	0.05273	25.0024	1.6453
Interaction				
S ₁ G ₀₀	6.11 c	0.10 h	359.0 d	18.47 e
S ₁ G ₂₀	6.67 a	0.26 g	402.4 d	25.03 d
S ₁ G ₄₀	6.67 a	0.29 g	436.9 d	27.90 d
S ₁ G ₆₀	6.27bc	0.25 g	433.3 d	27.43 d
S ₂ G ₀₀	6.67 a	0.28 g	535.5 c	34.47 c
S ₂ G ₂₀	6.67 a	0.56 d-f	563.3 bc	36.13 bc
S ₂ G ₄₀	6.67 a	0.54 ef	590.8 bc	37.63 a-c
S ₂ G ₆₀	6.51ab	0.46 f	586.3 bc	38.30 a-c
S ₃ G ₀₀	6.67 a	0.48 f	600.4 bc	38.60 a-c
S ₃ G ₂₀	6.67 a	0.67 cd	637.1 ab	40.60 ab
S ₃ G ₄₀	6.67 a	0.72 c	651.6 ab	41.77 ab
S ₃ G ₆₀	6.39abc	0.65 c-e	644.6 ab	40.87 ab
S ₄ G ₀₀	6.27bc	0.64 c-e	575.1 bc	36.93 bc
S ₄ G ₂₀	6.67 a	0.89 b	623.6 a-c	40.40 ab
S ₄ G ₄₀	6.67 a	0.88 b	651.1 ab	41.27 ab
S ₄ G ₆₀	6.67 a	1.15 a	691.0 a	42.67 a
LSD _{.05}	0.29	0.11	88.67	5.73
CV (%)	2.63	10.88	5.34	5.55

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.3.13.1. Influence of seed potato size on late blight of potato

There was no significant effect of late blight on different size of mother seed tuber up to 50 days (after sowing) DAP. But at 65 DAP, the percentage of late blight infection was highest in S₁ and the lowest percentage of late blight infection was in S₄ (Table 23). The thinner and less vigorous plants are more susceptible for late blight development. Increasing seed tuber size is linearly related with the plant vigourity, stem number per plant, leaf area coverage etc. The result is supported by the findings of Gulluoglu and Aroglu (2009), Sarker and Kabir (1989), Michael *et al.*, (2012), Mayakaduwa *et al.*, (2017) and Sultana *et al.*, (2001) in potato, where they stated that bigger seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites.

4.3.13.2. Effect of GA₃ on late blight of potato

There was no significant effect of different doze of GA₃ on mother seed tuber on late blight up to 50 days (after sowing) DAP. But at 65 DAP, the infection percentage of late blight was highest in G₄₀ and the lowest percentage of late blight was in G₆₀. These may be due to increase GA₃ increase the thinner stems per plant with large canopy coverage at 60 DAP, which might be susceptible for late blight (Table 23). The result is supported by the findings of Prasad *et al.*, (2013), Awati *et al.*, (2016), Virtanen *et al.*, (2013) and Loretta and Mikitel (1993) where gibberellic acid (GA) treatments significantly increased the number of sprouts per tuber and increased number of stem and ground coverage of potato.

4.3.13.3. Interaction effect of Seed potato size and GA₃ on late blight of potato

The interaction effect of Seed size and GA₃ on the of late blight infected plant percent at 50 DAP was not statistically significant, but significant on plant disease Incidence (PDI) (Table 23). The maximum PDI of late blight was in S₁G₂₀ and the minimum PDI of late blight was in S₄G₀₀. These may be due the using GA₃ on small size increase stem number/plant, increase the vegetative time with rapid growth and so the plants become thinner and succulent than control. The result is supported by the findings of Prasad *et al.*, (2013), Awati *et al.*, (2016), Virtanen *et al.*, (2013) and Loretta and Mikitel (1993) where they stated that gibberellic acid (GA) increased the number of stem and ground coverage of potato

4.3.14.1. Effect of seed potato size on the plant disease incidence (PDI) of late blight of potato

The statistical difference was found at 65 DAP among the different size of mother seed tuber and ranges from 1.05 to 1.25 (Table 23). The maximum PDI of late blight was in S₁ and the minimum PDI of late blight was in S₄. These may be due to large seeds are enable to produce more difference of vigorous plant then smallest seed. The weak plants are more susceptible for late blight development. Increasing seed tuber size is linearly related with the plant vigourity, stem number per plant, leaf area coverage etc. the result is supported by the findings of Gulluoglu and Aroglu (2009), Sarker and Kabir (1989), Michael *et al.*, (2012), Mayakaduwa *et al.*, (2017) and Sultana *et al.*, (2001) in potato, where they stated that bigger seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites.

4.3.14.2. Effect of GA₃ on the plant disease incidence (PDI) of late blight

The on the plant disease Incidence (PDI) of late blight was found statistical difference at 65 DAP among the dozes of GA₃, and ranges from 1.13 to 1.62. The maximum PDI of late blight was in G₂₀, which was similar with G₀₀. The minimum PDI of late blight was in G₆₀ (Table 23). GA₃ increase the stems per plant with large canopy coverage, where area and natural resource are fixed, so the plants become weak and susceptible for late blight. The result is supported by the findings of Prasad *et al.*, (2013), Awati *et al.*, (2016), Virtanen *et al.*, (2013) and Loretta and Mikitzel (1993) where they stated that gibberellic acid (GA) significantly increased the number of stem and ground coverage of potato.

4.3.14.3. Interaction effect of Seed size and GA₃ on natural late blight at 65 DAP

The interaction effect of Seed size and GA₃ on the disease percentage and the plant disease incidence (PDI) of late blight at 65 DAP is statistically significant (Table 23). The maximum percent (2.23) of late blight was in S₂G₄₀ and the minimum percent (0.61) of late blight was in S₃G₂₀. On the other hand, the maximum PDI (25.23) of late blight was in S₂G₄₀ and the minimum PDI (21.11) of late blight was in S₃G₂₀. After use of fungicides to control late blight, the GA₃ treated plots can recover quickly due to elongation and cell division enhanced by GA₃. The result is corroborated with the findings of El-hamady (2017) where he stated that GA₃ markedly increased plant height, chlorophyll content, foliage fresh and dry weight g/plant.

Table 23. Effect of seed size and GA₃ on late blight of seed potato

Treatments	%LB 50DAP	PDI. 50DAP	% LB 65DAP	PDI 65DAP
A. Seed Size				
S ₁	0.32	21.50	1.60 a	26.18(1.25) a
S ₂	0.16	20.67	1.46 ab	23.50(1.18) ab
S ₃	0.16	22.08	1.14 b	22.93(1.11) ab
S ₄	0.20	21.17	1.26 b	20.25(1.05) b
LSD _{.05}	NS	NS	0.31	0.13
B. GA₃ Conc.				
G ₀₀	0.22	20.25	1.47 ab	23.32(1.21) ab
G ₂₀	0.18	21.92	1.24 bc	24.32(1.09) a
G ₄₀	0.27	21.92	1.62 a	22.05(1.25) bc
G ₆₀	0.17	21.33	1.13 c	23.17(1.05) c
LSD _{.05}	NS	NS	0.31	0.13
Interaction				
S ₁ G ₀₀	0.44	20.67 a-c	1.59 a-c	24.54(1.25) a-c
S ₁ G ₂₀	0.28	24.00 a	1.95 ab	30.55 (1.39) ab
S ₁ G ₄₀	0.36	20.00 a-c	1.66 a-c	21.06(1.29) a-c
S ₁ G ₆₀	0.21	21.33 a-c	1.19 cd	28.56(1.05) cd
S ₂ G ₀₀	0.09	19.00 bc	1.33 bc	24.08(1.15) bc
S ₂ G ₂₀	0.10	20.33 a-c	1.13 cd	23.38(1.06) cd
S ₂ G ₄₀	0.30	23.00 ab	2.23 a	25.23(1.47) a
S ₂ G ₆₀	0.14	20.33 a-c	1.14 cd	21.30(1.06) cd
S ₃ G ₀₀	0.21	24.00 a	1.53 bc	23.84(1.23) a-c
S ₃ G ₂₀	0.12	21.00 a-c	0.61 d	21.11(0.78) d
S ₃ G ₄₀	0.19	22.00 ab	1.25 b-d	21.29(1.11) bc
S ₃ G ₆₀	0.15	21.33 a-c	1.17 cd	25.46(1.08) c
S ₄ G ₀₀	0.12	17.33 c	1.42 bc	20.83(1.19) a-c
S ₄ G ₂₀	0.21	22.33 ab	1.25 b-d	22.22(1.11) bc
S ₄ G ₄₀	0.25	22.67 ab	1.32 b-d	20.60(1.15) bc
S ₄ G ₆₀	0.21	22.33 ab	1.03 cd	17.36(1.01) cd
LSD _{.05}	NS	3.56	0.62	0.26
CV (%)		10.00	27.02	13.63

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Figures in parenthesis indicate transformed values.

4.3.15.1. Effect of seed potato size on the elongation of potato

The effect of mother seed tuber size on the elongation percentage of potato tuber was varied significantly among the treatments. The maximum percentage of potato tubers were elongated by using S₃ and the minimum percentage of potato tubers were elongated by using S₁ (Table 24). The elongation occurred might be due to most vigour of the plant. The large size of seed has more vigorous effect than smallest size and over size tuber. The result is supported by the findings of Michael *et al.*, (2012), he stated that the large size seed tubers, with their relatively larger food reserves, produced large plants which established faster and produced vigorous stems, which increases the efficiency of biomass partitioning to the tubers.

4.3.15.2. Effect of GA₃ on the elongation of potato

The effect of GA₃ on the elongation percentage of potato tuber was statistically significant among the treatments. The maximum percentage of potato tubers were elongated by using G₂₀ and the minimum percentage of potato tubers were elongated by using G₀₀ (Table 24). The GA₃ has cell division and elongation effect of cell. This result is supported by Alexopoulos *et al.*, (2006), where they reported that the plants that had been treated with GA₃ early in the growth cycle consistently produced more elongated tubers (37.3%) of total tubers in the autumn crop and 31.6% in the spring crop) than the control or other PGR treatments.

4.3.15.3. Interaction effect of seed potato size and GA₃ on the elongation of potato

The interaction effect of mother seed tuber size and GA₃ on the elongation percentage of potato tuber was statistically significant. The maximum percentage of potato tubers were elongated by using S₃G₆₀ which was statistically similar with S₄G₄₀. The minimum percentage of potato tubers were elongated by using S₁G₀₀ (Table 24). The increasing seed tuber size with GA₃ cause rapid growth and more vigour of the crops. This result is supported by Alexopoulos *et al.*, (2006), they reported that the plants that had been treated with GA₃ early in the growth cycle consistently produced more elongated tubers (37.3%) of total tubers in the autumn crop and 31.6% in the spring crop) than the control or other PGR treatments.

Table 24. Effect of seed size and GA₃ on the elongation of seed tubers

Treatments	% Elongated tuber
A. Seed Size	
S ₁	24.00 (24.24) c
S ₂	23.17 (24.83) c
S ₃	48.42 (37.58) a
S ₄	34.33 (31.13) b
LSD _{.05}	4.17
B. GA₃ Conc.	
G ₀₀	0.00 (2.69) d
G ₂₀	59.25 (48.68) a
G ₄₀	23.17 (26.46) c
G ₆₀	47.50 (39.95) b
LSD _{.05}	4.17
Interaction	
S ₁ G ₀₀	0.00 (1.91) h
S ₁ G ₂₀	65.00 (51.86) ab
S ₁ G ₄₀	7.67 (15.36) g
S ₁ G ₆₀	23.33 (27.84) ef
S ₂ G ₀₀	0.00 (2.68) h
S ₂ G ₂₀	41.00 (38.20) cd
S ₂ G ₄₀	20.00 (25.52) ef
S ₂ G ₆₀	31.67 (32.94) de
S ₃ G ₀₀	0.00 (3.02) h
S ₃ G ₂₀	56.00 (46.78) bc
S ₃ G ₄₀	51.00 (43.98) bc
S ₃ G ₆₀	86.67 (56.53) a
S ₄ G ₀₀	0.00 (3.16) h
S ₄ G ₂₀	75.00 (57.88) a
S ₄ G ₄₀	14.00 (20.99) fg
S ₄ G ₆₀	48.33 (42.48) c
LSD _{.05}	8.34
CV (%)	16.98

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. Figures in parenthesis indicate transformed values.

4.3.16. Effect of GA₃ on potato mosaic virus (PMV)

The maximum percentage of potato mosaic virus at G₀₀ and minimum percentage of potato mosaic virus was found at G₂₀, G₄₀, G₆₀ at 45 DAP (Fig 3). At 60 DAP, the maximum % of PMV infected plant was found at G₆₀ and minimum % of PMV infected plant was found at G₂₀. At 75 days after planting, the maximum % of PMV infected plant was found at G₆₀ and minimum % of PMV infected plant was found G₂₀. The low concentration (20ppm) of GA₃ can increase the resistance of potato to PMV, but higher concentration of GA₃ can decrease the resistance of potato to PMV. This might be due to use of higher concentration GA₃ increase more number of thinner stem and succulent leaf per plant. And this condition is more suitable for insects and aphid. The results is supported by the findings of Prasad *et al.* (2013) and Alexopoulos, *et al.* (2006), where they stated that GA₃ application significantly increased plant height and the number of thinner stems per plant.

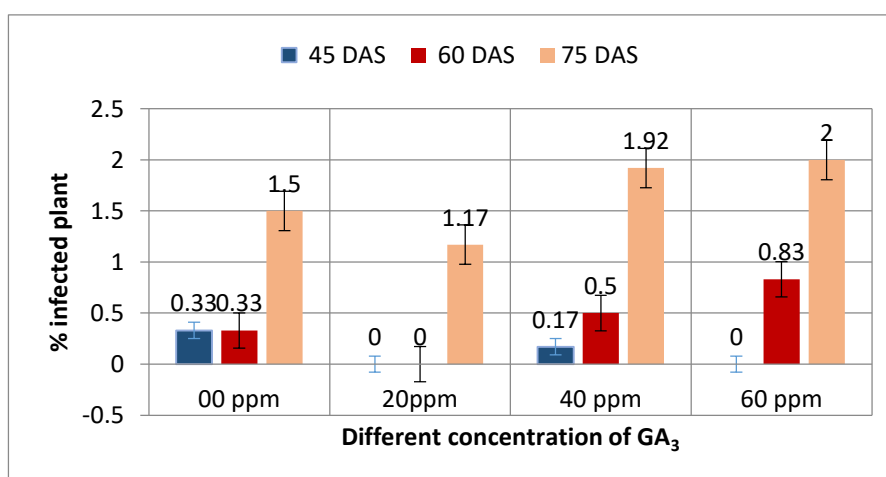


Fig 3. Effect of GA₃ on potato mosaic virus

4.3.17. Effect of GA₃ on infection potato virus Y (PVY) of potato

There was no significant difference was found in case potato virus Y at different stage of field potato where different concentrated GA₃ were used (Fig. 4).

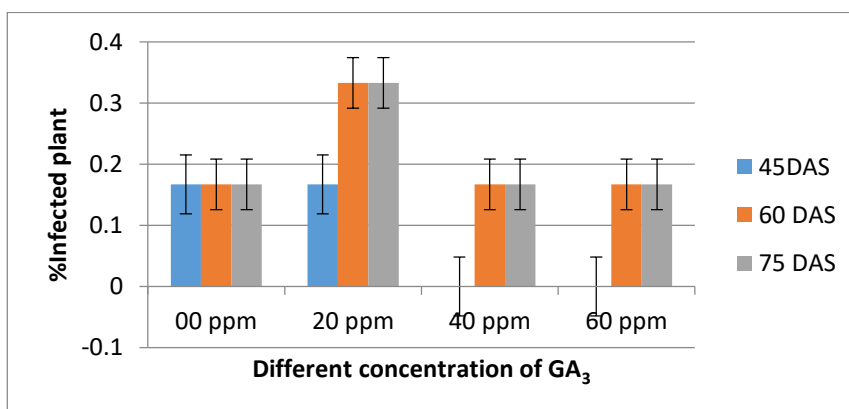


Fig 4. Effect of GA₃ on potato virus Y

4.3.18. Effect of GA₃ on potato leaf roll virus (PLRV)

From the graph (Fig 5), the maximum percentage of potato leaf roll virus was found in G₆₀ and minimum percentage of potato leaf roll virus was found in G₂₀ at 75 days after planting. But there was no significant differences among the different concentration of GA₃ to treat seed tuber.

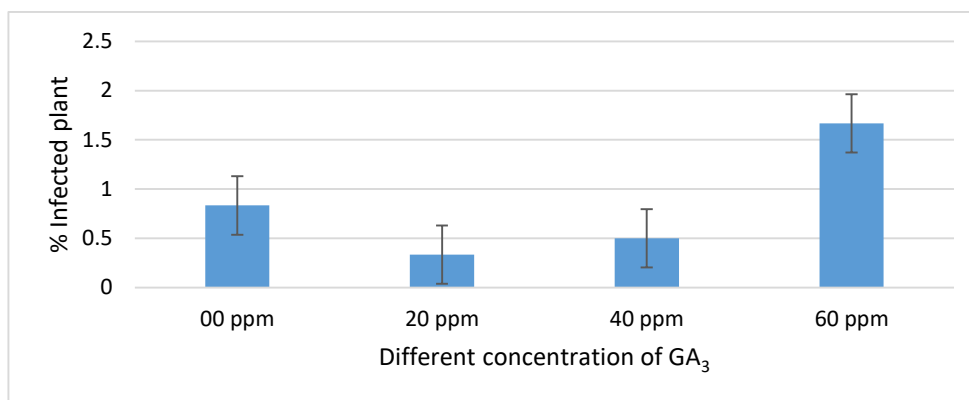


Fig.5. Effect of GA₃ on potato leaf roll virus (75 DAP)

4.3.19. Effect of seed size on potato leaf roll virus (PLRV)

The maximum % of PLRV infected plant was found in S₁ and minimum % was found from S₄ which was identical with S₂ and S₃ at 75 DAP (Fig 6). The virus are transmitted by insects whose love the succulent and green plant part. The smallest seeds produced comparatively thinner stem and more succulent. But large seed tuber performed vigorous plants. The result is supported by the findings of Mayakaduwa *et al.*, (2017) and Gulluoglu and Aroglu (2009); where they stated that larger seeds positively affected all growth and the large size seed tubers, with their relatively larger food reserves, produced large plants which established faster and produced vigorous stems.

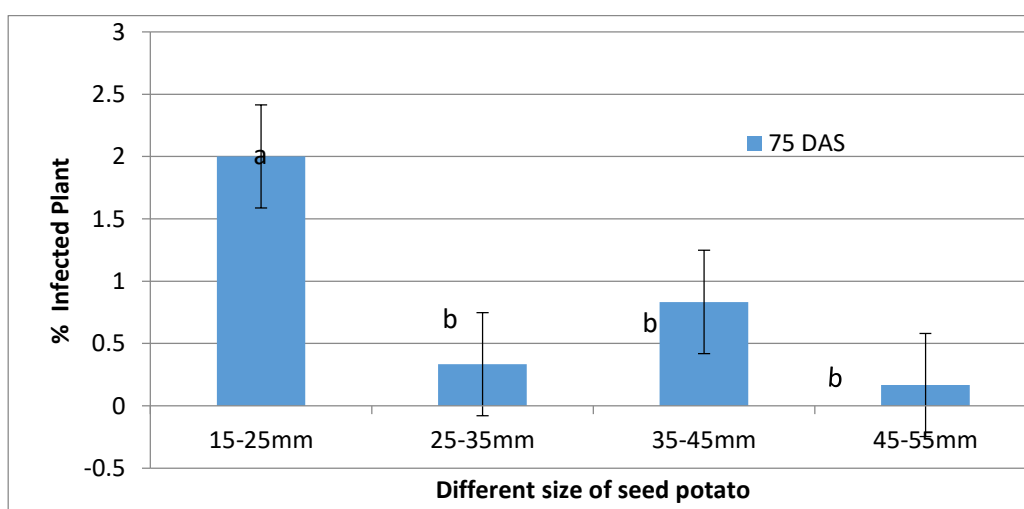


Fig 6: Effect of seed potato size on potato leaf roll virus

4.3.20. Correlations among different growth parameters, yield components and yield in plots of different seed potato size and different GA3 concentrations

Plant height of 30 DAP was positively correlated with plant height at 45, 60 and 75 DAP (Table 25). Plant height 45 DAP was positively correlated with plant height at 60 and 75 DAP, stem number per hill at 30, 45, 60 and 75 DAP, leaf area coverage at 30, 45, 60 and 75 DAP, Population/m² canopy weight (kg), tuber weight/plant (g) and yield. Plant height 60 DAP, is positively correlated with Plant height at 75 DAP. Plant height 75 DAP is positively correlated with stem number per hill at 45 DAP and Population/m². stem number per hill at 30 DAP, is positively correlated with stem number per hill at 45, 60, 75 DAP, leaf area coverage at 30, 45, 60, 75 DAP, Population/m², Canopy out (kg), tuber number per plant, tuber weight, and Yield. Stem number per hill at 60 DAP, is positively correlated with stem number per hill at 60 and 75 DAP, leaf area coverage 45, 60, 75 DAP, canopy weight, tuber number per plant, tuber weight per plant and Yield. Stem number per hill at 75 DAP, is positively correlated with leaf area coverage at 45, 60 and 75 DAP, and Canopy weight, tuber number per plant, tuber weight per plant and Yield. Leaf area coverage (LAC) 30 DAP is positively correlated with LAC 45, 60 DAP, Canopy weight, tuber weight per plant and Yield. Leaf area coverage (LAC) 45 DAP is positively correlated with LAC 60 and 75 DAP, Population/m², tuber number per plant, tuber weight per plant and Yield. Leaf area coverage (LAC) 60 DAP is positively correlated with LAC 75 DAP, population per m², Canopy weight, tuber number per plant, tuber weight per plant and Yield. Leaf area coverage (LAC) 75 DAP is positively correlated with Population per m², Canopy weight, tuber number per plant, tuber weight per plant and Yield. Population per m² is positively correlated with Canopy weight, tuber number per plant, tuber weight per plant and Yield. Canopy weight is positively correlated with tuber number per plant, tuber weight per plant and Yield. Tuber number per plant is positively correlated with, tuber weight per plant and Yield. Tuber weight/plant is positively correlated with Yield.

Table 25. Correlation coefficients among different growth parameters, yield components and yield in plots of different seed potato size and different GA3 concentrations

	PH ₁	PH ₂	PH ₃	PH ₄	SH ₁	SH ₂	SH ₃	SH ₄	LAC ₁	LAC ₂	LAC ₃	LAC ₄	Pop	CanWt	Tn	TuWt	Yield
PH ₁	1	0.75**	0.69 **	0.59*	0.07	0.01	0.02	0.02	0.30	0.14	0.20	0.12	0.32	0.03	-0.08	0.19	0.16
PH ₂		1	0.57 *	0.50*	0.55*	0.50*	0.49*	0.49*	0.68**	0.70**	0.70**	0.46*	0.56*	0.50*	0.39	0.70**	0.69**
PH ₃			1	0.84**	0.30	0.32	0.33	0.33	-0.01	0.25	0.37	0.41	0.35	0.32	0.34	0.14	0.12
PH ₄				1	0.27	0.29**	0.29	0.296	-0.229	0.10	0.35	0.40	0.52*	0.28	0.399	0.02	-0.01
SH ₁					1	0.99**	0.99**	0.98**	0.49*	0.79**	0.78**	0.54*	0.45*	0.99**	0.86**	0.73**	0.68**
SH ₂						1	0.997**	0.99**	0.43	0.78**	0.77**	0.51*	0.43	0.99**	0.86**	0.72**	0.67**
SH ₃							1	0.99**	0.41	0.77**	0.77**	0.51*	0.41	0.99**	0.86**	0.71**	0.65**
SH ₄								1	0.39	0.76**	0.75**	0.51*	0.41	0.99**	0.86**	0.69**	0.64**
LAC ₁									1	0.78**	0.59*	0.34	0.33	0.43**	0.21	0.804**	0.82**
LAC ₂										1	0.92**	0.68**	0.56*	0.77	0.71**	0.898**	0.90**
LAC ₃											1	0.75**	0.74**	0.76**	0.81**	0.81**	0.82**
LAC ₄												1	0.79**	0.51**	0.68**	0.55*	0.57*
Pop.													1	0.41*	0.51**	0.497*	0.53*
CanWt														1	0.87**	0.68**	0.63**
Tu.No															1	0.57*	0.55*
TuWt																1	0.98**
Yield																	1

Correlation coefficients indicates *= 5% level significant, and **=1% level significant *** = highly level significant,

PH₁=Plant height at 30 DAP, PH₂=Plant height at 45 DAP, PH₃=Plant height at 60DAP, PH₄=Plant height at 75 DAP, SH₁= Stem number per hill at 30 DAP, SH₂= Stem number per hill at 45 DAP, SH₃= Stem number per hill at 60 DAP, SH₄= Stem number per hill at 75 DAP, LAC₁= LAC at 30 DAP, LAC₂= LAC at 30 DAP, LAC₃= LAC at 30 DAP, LAC₄= LAC at 30 DAP, Pop= population per m², CanWt= canopy weight (kg), TuNo = Tuber number per plant, TuWt = Tuber weight per plant (g) and Yield = Yield (ton/h)

4.3.21. Functional relationship of GA₃ concentration with tuber yield of potato

From the functional relationship between GA₃ and yield of potato (Fig.-7), for maximum yield of potato the optimum level of GA₃ concentration can be calculated as below

Optimum level of GA₃ concentration for maximum yield

$$Y = \frac{-b}{2c}, \text{ Here, } b = 0.200 \text{ and } c = -0.002$$

$$Y = \frac{-b}{2c} = \frac{-0.200}{2 \times (-0.002)} = 50 \text{ ppm GA}_3$$

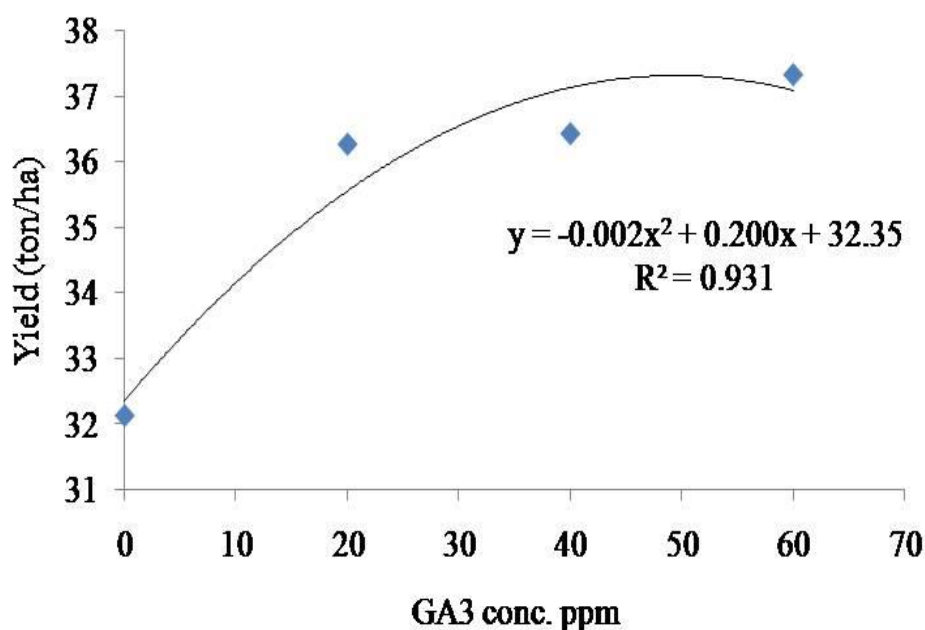


Fig. 7. Functional relationship between GA₃ and tuber yield of potato

The maximum yield for predicted GA₃

$$y = -0.002x^2 + 0.200x + 32.35$$

$$= -0.002(50)^2 + 0.200 \times 50 + 32.35$$

$$= 37.35 \text{ ton/ha}$$

From the regression equation tuber yield increase 1 g with increase of GA₃ of 0.002 ppm. The predicted maximum yield (37.35 ton/ha) were obtained with 50 ppm GA₃.

Experiment 4. Degradation assessment of different categories of seed potato

4.4.1. Effect of different categories seed potato on germination percentage

The emergence percentage at 30 DAP was varied significantly in first year planting. The minimum germination percentage was recorded from minituber and maximum emergence percentage was recorded from breeder seed and Foundation seed (Fig 8). The size of minituber in 1st generation was small compared to all other categories of seed potatoes. This may be affect the seed emergence. The result is corroborated with the results of Mayakaduwa *et al.*, (2017), Michael *et al.*, (2012); and Gulluoglu and Aroglu (2009); where they state that size of the seed tubers influenced emergence of seed potato. They also reported that larger tubers had an advantage for vigorous early growth and developments. In 2nd generation, collected seeds from 2014-15 season were sown and no significant differences was observed in emergence percentage at 30 DAP. The minituber and the foundation seed performed maximum emergence percentage, but certified seed showed minimal percentage of emergence. During 2016-17, collected seeds of 2nd generation were sown in the field and significant differences on emergence was not found. The minituber performed maximum emergence percentage and minimal percentage of emergence was counted from certified seed. From the result stated above it was clear that advancing generation gradually decrease the emergence percentage (Fig 8). The similar observation was reported by Gundi *et al.*, (2011) where they found that seedling emergence was not differ significantly in advanced generation of seed potato.

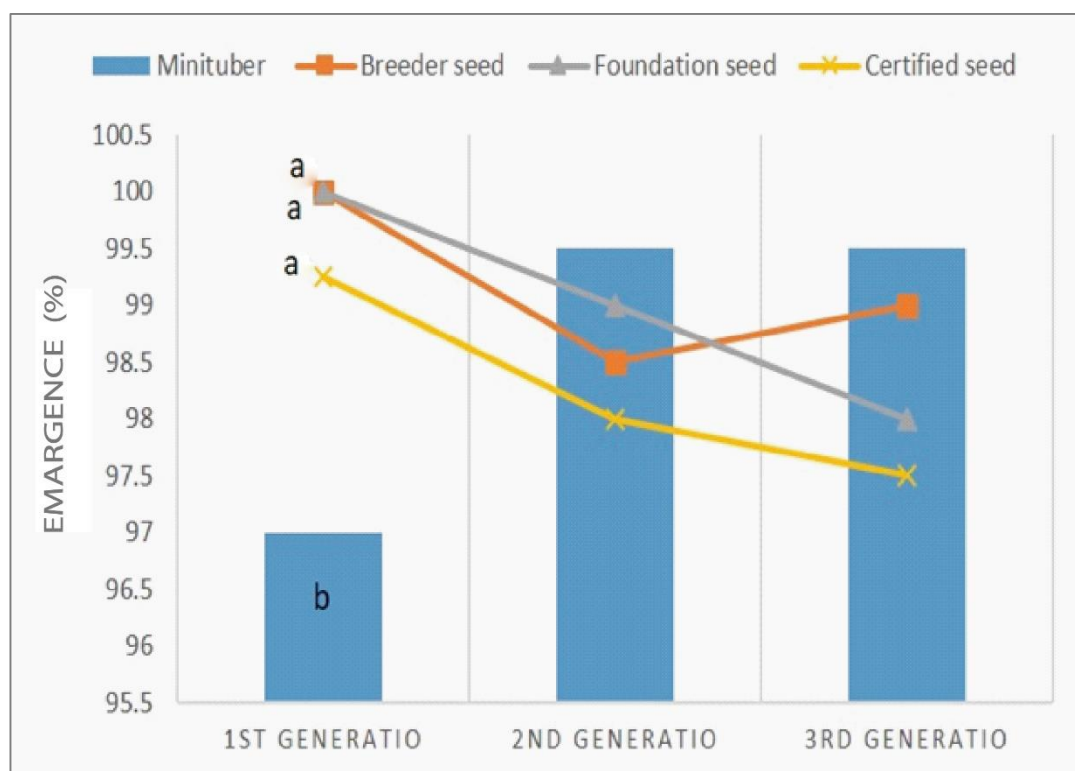


Fig. 8. Emergence of different categories of seed potatoes in advancing generation

4.4.2. Status of different categories seed potato on plant height

The plant height was almost similar as observed during 2014-15, 2015-16 and 2016-17 cropping season in minituber, breeder seed, foundation seed and certified seed (Fig 9). In 2014-15 season, different categories seed potatoes performed non-significant plant height. It ranged from 74.0 cm to 76.8 cm. The 2nd generations of different categories seed potatoes performed non-significant in plant height and ranged from 68.5 to 70.0 cm. The 3rd generations of different categories seed potatoes performed significant variation in plant height and ranged 53.7 cm to 66.4 cm. The highest plant height measured from minituber and the lowest plant height measured from certified seed (Fig 9). In all generation, the plant height was decreased at subsequent year. These results is aggregated with the findings of Sarker *et al.*, (2018), Hussain *et al.*, (1978) and Tien *et al.*, (1982) where they stated that degeneration occurred in successive cropping season and affect the plant height.

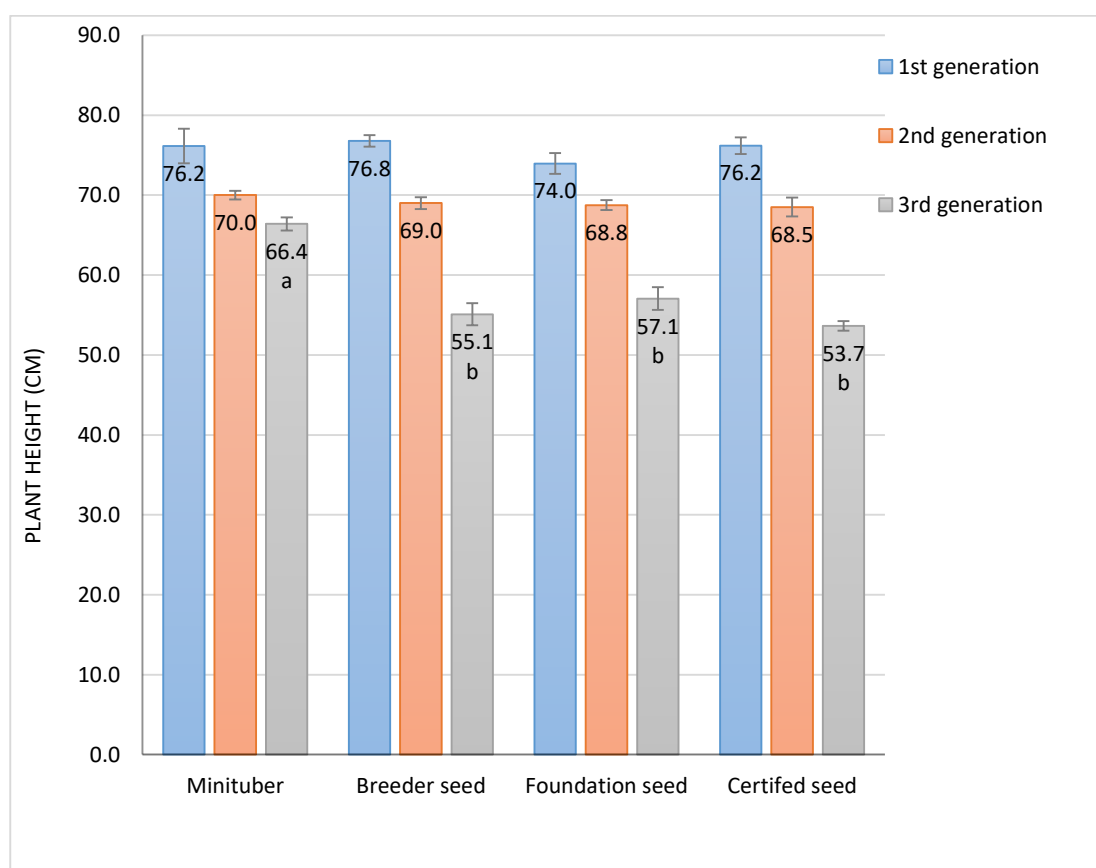


Fig. 9. Plant height (cm) at different category of potato in advancing generation

4.4.3. Status of different categories seed potato on stem number

Stem number per hill was not differ significantly by advancement of generation of seed potato. In first year, 2014-15, the different categories of seed potatoes were not differ on stem number per hill and ranged from 3.1 to 3.8. In 2nd generations of different categories seed potatoes

performed non-significant in stems per hill and ranged from 3.4 to 3.8. Similarly, in 2016-17 cropping season, the 3rd generations of different categories seed potatoes had no significant effect on stems number per hill and ranged from 3.4 to 3.7 per hill (Fig 10). The stem number per hill is influenced by variety and size of tuber. As the seeds of different categories were similar variety and more or less unique size of seed were used so the significant variation was not found in stem number per hill.

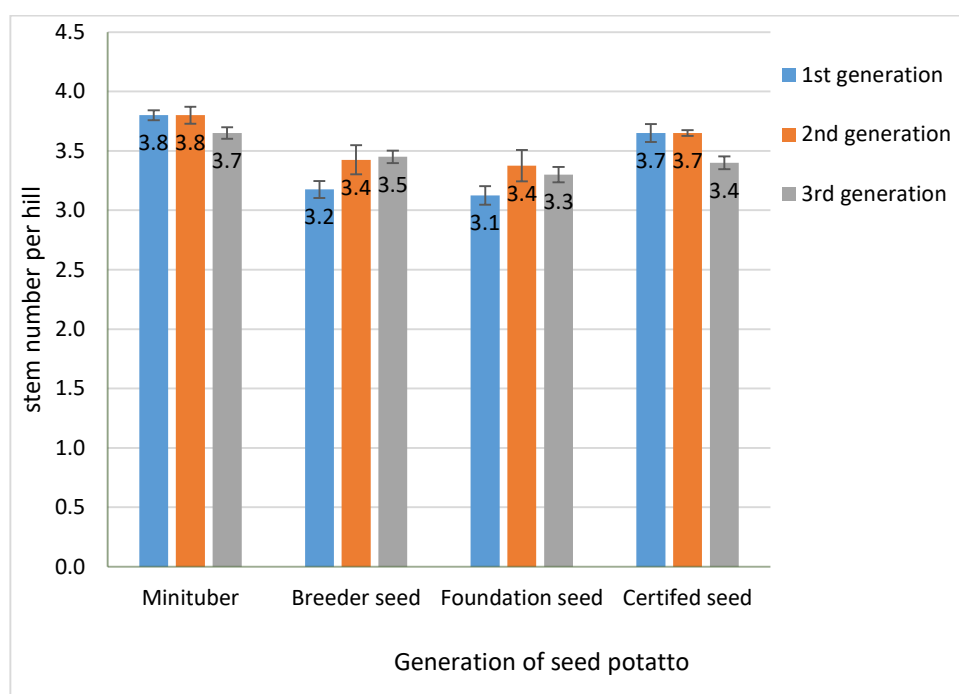


Fig. 10. Stem number per hill at different category of potato in advancing generation

4.4.4. Status of different categories of seed potato on leaf area coverage

The 1st generations of different categories of seed potatoes were effect significantly on leaf area coverage. The maximum LAC (98.30 %) was recorded from certified seed and the minimum LAC (90.80 %) was recorded from minituber (Fig. 11). The size of certified seed was comparatively larger than minitubers. Seed size influenced the leaf area coverage of potato. The LAC was almost complete only in the plots derived from normal tubers and decreased with the size of the mother tubers. Similar results was reported by Ranalli *et al.*, (1994) where they stated that the LAC was almost complete only in the plots derived from normal tubers and decreased with the size of the mother tubers.

In 2nd and 3rd generation, the different categories of seed potato performed non-significant leaf area coverage and ranged from 94.00% to 96.00% and 84.50% to 91.30%, respectively. But,

the LAC was decreased with advancing generation, might be due to decrease plant height in advancing generations (Fig. 4). These results are supported by the findings of Ganudi *et al.*, (2011) where they found that different generation of potato has no significant effect on ground coverage.

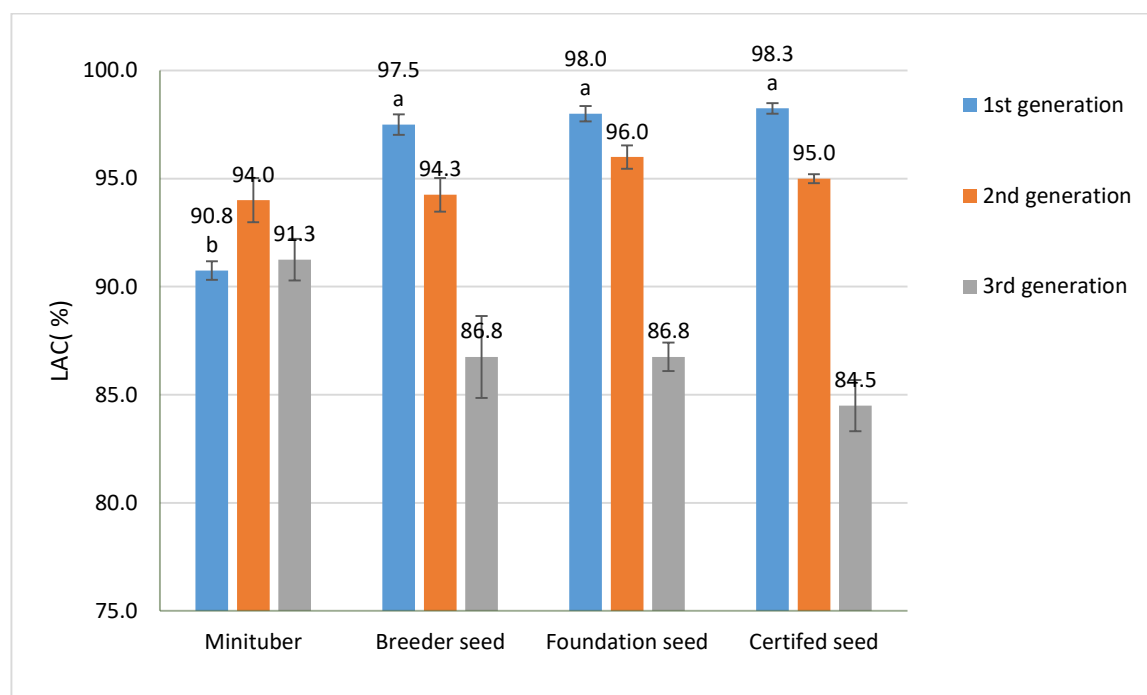


Fig. 11. Leaf area coverage at different category of potato in advancing generation

4.4.5. Performance of different categories of seed potato in tuber number

The tuber number per hill was not varied significantly among the different categories of seed potato in 1st generation and ranges from 9.6 to 10.8. In the 2nd generation of the different categories of seed potato were produced statistically significant number of tubers per hill. The maximum number of tuber per hill (12.07) was recorded from foundation seed, which was statistically similar with the minituber and breeder seed. The minimum number of tuber (9.9) per hill was counted from certified seed (Fig. 12).

In the 3rd generations of different categories of seed potatoes also performed statistically differences in tubers per hill. The maximum number of tubers (11.12) per hill were produced by breeder seed which was similar with minituber. The minimum tuber number per hill (9.95) was found from certified seed (Fig 12). The advancing generation of potato seeds increase the incidence of different seed borne diseases and might be cause of decreasing tuber number per hill. The results are corroborated with the similar report of Sarker *et al.*, (2018), Gunadi *et al.*, (2011) and Rahman and Akanda (2010).

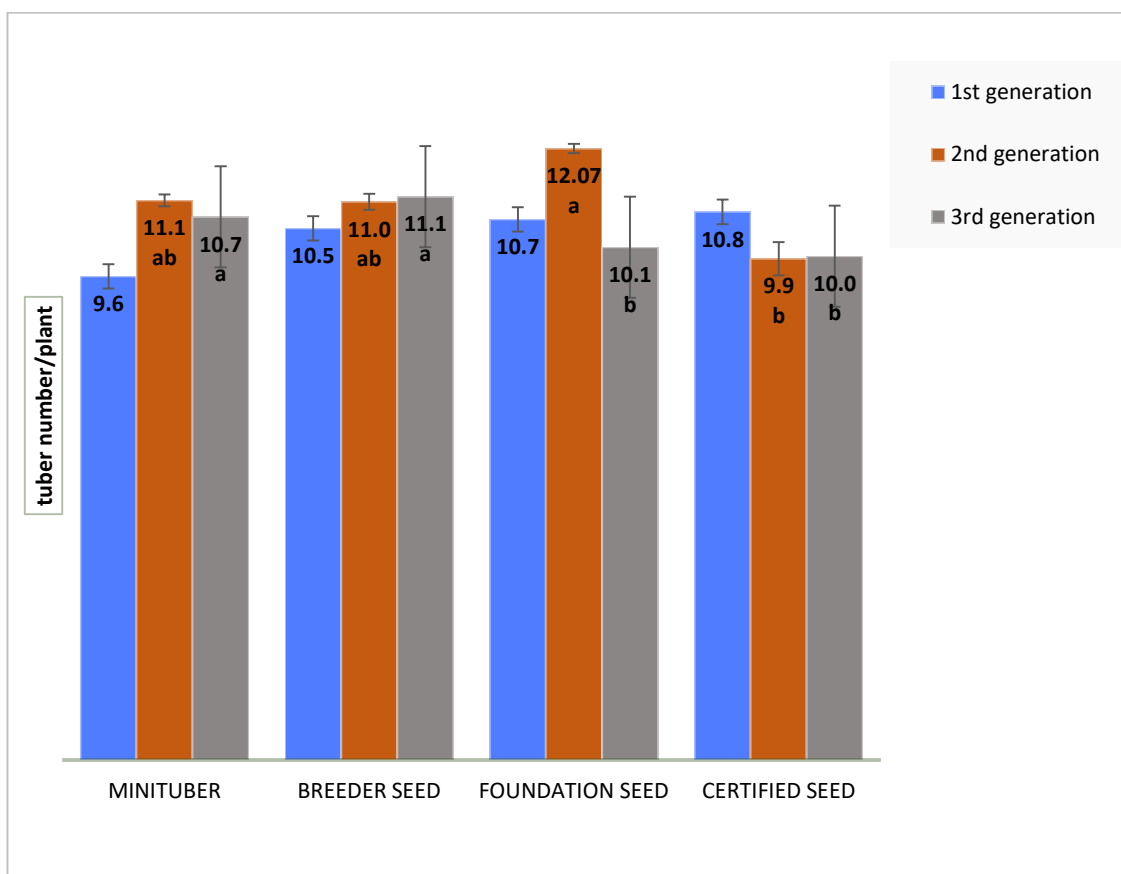


Fig. 12. Tuber number per plant at different category of potato in advancing generation

4.4.6. Performance of different categories of seed potato on tuber weight

In 1st generation, the effect of different categories of seed potatoes on tuber weight per hill was significant. The highest tuber weight (520 g) was counted from seed of certified seed which was statistically similar with foundation seed and followed by breeder seed. The lowest tuber weight (358 g) per hill was counted from minituber (Fig 13). The seed tuber size of certified seed was comparatively larger than minitubers, may cause higher tuber weight per plant. The result is supported by the findings of Sultana *et al.*, (2001), Verma *et al.*, (2007) and Gulluoglu and Aroglu (2009) where they stated that seed size effects on yield of potato.

In 2nd generation, the effect of different categories of seed potato on tuber weight per hill was not significant and ranged from 515.08 g to 571.98 g.

In the 3rd generation of different categories of seed potatoes performed significant variation on tuber weight per hill and ranges from 345.8 g to 400.32 g. The uppermost tuber weight per hill was found at minituber and bottommost was counted from certified seed (Fig 13). The maximum weight were found in advancement of minituber might be due to less infected by different diseases of potato. The results are supported by the similar report of Sarker *et al.*, (2018), Gunadi *et al.*, (2011) and Rahman and Akanda (2010).

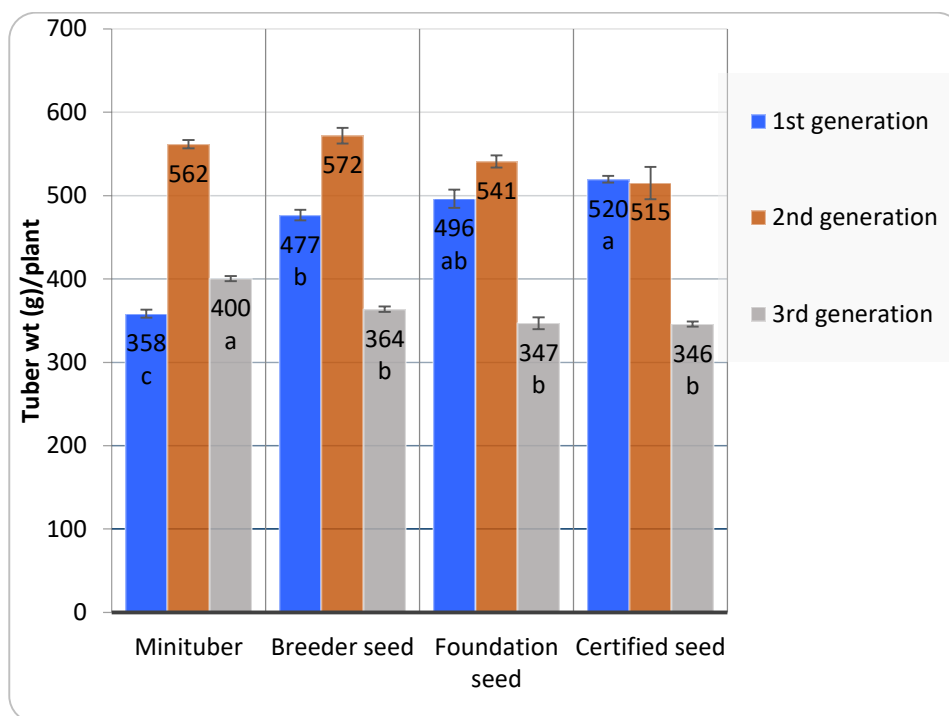


Fig. 13. Tuber weight per plant (g) at different category of potato in advancing generation

4.4.7. Status of grading of potato collected from 1st generation of different categories of seed potato

In 1st generation, the effect of different categories of seed potato on the tuber size distribution are presented in Fig 14 and Fig 15. The significant differences was not found in smallest (10-28 mm) and “A” grade (28- 41mm) tubers. The number of smallest size seed and “A” grade size seed tuber ranged from 1.9 to 2.4 and 2.8 to 3.5 per hill, respectively. The weight of smallest size seed and “A” grade size seed tuber per hill ranges from 11 to 16 and 69 to 96 per hill, respectively. Considering “B” grade (41 to 55 mm) and oversize (>55 mm) tuber per hill, significant variation was found among treatments. The highest B grade tuber number (5.2) per hill was found in certified seed which is followed by breeder and foundation seed. The maximum B grade tuber weight (316 g) per hill was counted from certified seed which was statistically similar with breeder seed and foundation seed. The minimum number (3.1) and weight (316 g) of “B” grade tuber per hill was counted from minituber. The maximum oversize tuber number (1.1) per hill was recorded from the certified seed and the minimum tuber number (0.5) per hill was counted from minituber (Fig 15). The maximum oversize tuber weight (128 g) was found from foundation seed and the minimum oversized weight (61 g) per hill were found in minituber (Fig. 15).

The 1st generation of minitubers were comparatively smaller than others. For these reason, it may produce comparatively lower tuber number and weight per hill. The results was supported by the similar report of Huda (2012) and Gunadi *et al.*, (2011).

4.4.8. Status of grading of potato collected from 2nd generation of different categories of seed potato

In the 2nd generation, tuber grading on the basis number and weight was not varied significantly among the different categories of seed potato. The smallest size tuber per hill was ranges from 1.0 to 1.7 in number and 7 to 12 g in weight. In case of “A” grade seeds per hill was ranges from 2.7 to 3.5 in number and 69 to 84 g in weight. In case of “B” grade seed per hill, the range was 5.4 to 6.4 in number and 354 to 381 g in weight. The oversize tuber number and weight per hill were ranges from 0.5 to 0.8 and 62 to 107 g, respectively (Fig 16 and Fig 17). Similar pattern of seed tuber distribution was followed by Huda (2012) and Gundi *et al.*, (2011) where they found that the yielded tubers from different generations of seed potato was not effect significantly on tuber grading. The result was also supported by the finding of previous years experiment.

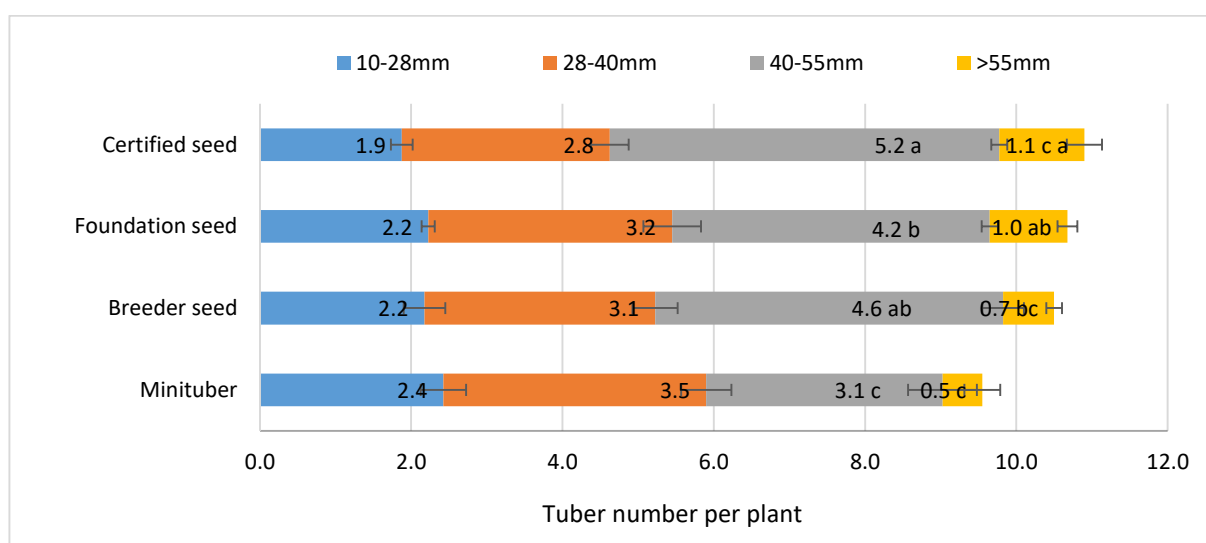


Fig. 14. Grading (number basis) of potato collected from 1st generation of different categories of seed potato

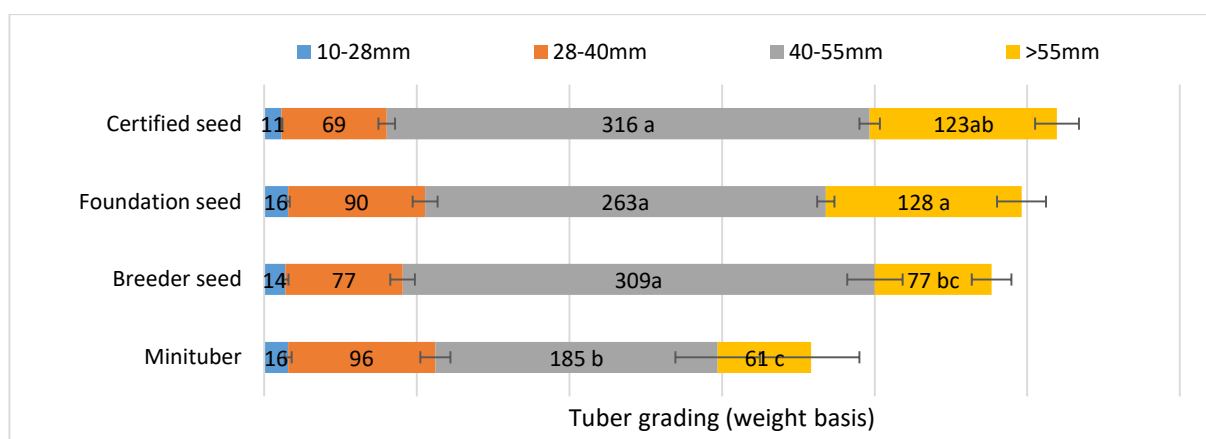


Fig. 15. Grading (weight basis) of potato collected from 1st generation of different categories of seed potato

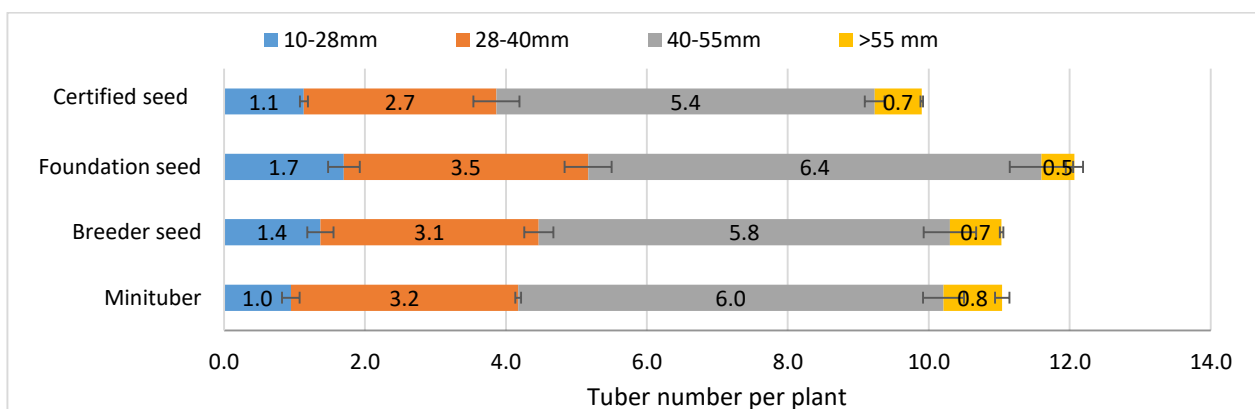


Fig. 16. Grading (number basis) of potato collected from 2nd generation of different categories of seed potato

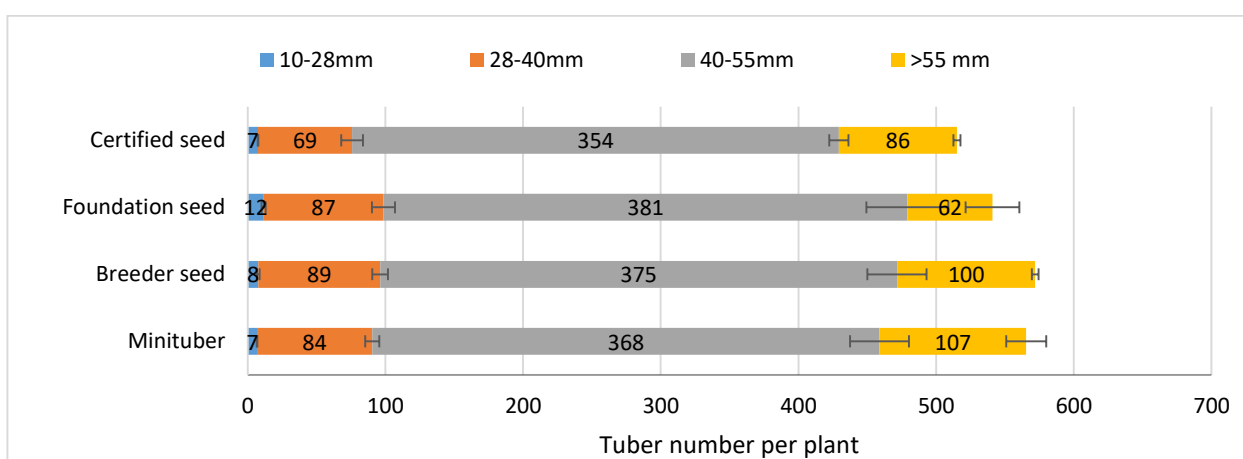


Fig. 17. Grading (weight basis) of potato collected from 2nd generation of different categories of seed potato

4.4.9. Status of grading of potato collected from 3rd generation of different categories of seed potato

In the 3rd generation, tuber grading on the basis number and weight was not varied significantly among the different categories of seed potato. The smallest size tuber per hill was ranges from 2.0 to 3.1 in number and 15 to 21 g in weight. The “A” grade seeds per hill was ranges from 3.4 to 4.3 in number and 87 to 110g in weight. In case of “B” grade seed per hill, the range was 3.5 to 4.3 in number and 202 to 262 g in weight. The oversize tuber number and weight per hill were ranges from 0.2 to 0.3 and 17 to 34 g, respectively. All the seeds of different generations were similar variety and produces in similar environmental condition. So variation was not found in subsequent years of different categories of seed potato. Similar pattern of seed tuber distribution was followed by Huda (2012) and Gundi *et al.*, (2011) where they found that the yielded tubers from different generations of seed potato was not effect significantly on tuber grading. The result was also supported by the finding of two previous years experiment.

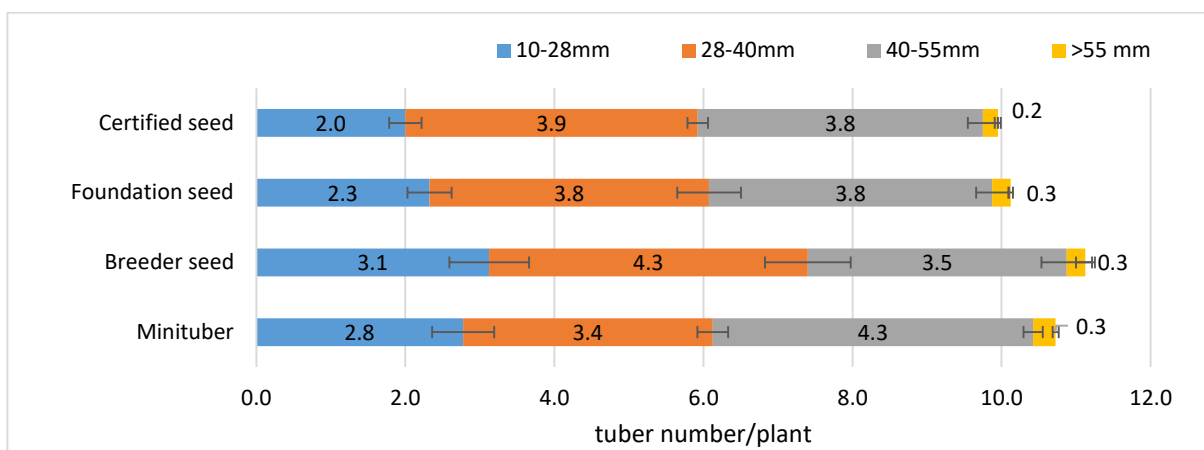


Fig. 18. Grading (number basis) of potato collected from 3rd generation of different categories of seed potato.

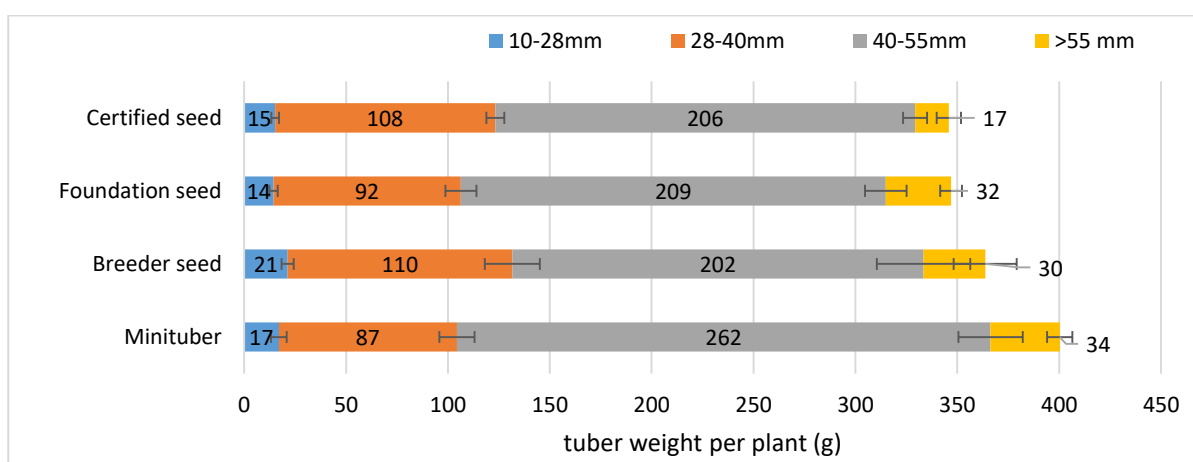


Fig. 19. Grading (weight basis) of potato collected from 3rd generation of different categories of seed potato.

4.4.10. Status of different categories of seed potatoes on wilt in advancing generation

Effect of different categories of potatoes on field infestation of bacterial wilt in consequent generation was significant. In 1st generation, the infestation of wilt was significant among the different categories of seed potatoes. The maximum 1.42 % plants were naturally infected in only certified seeds. In 2nd generation, infestation of wilt were also statistically significant among the advanced generation of different categories seed potatoes. The highest 1.88 % wilt infected plants were counted from certified seed. In 3rd generation, the maximum 4.65% wilting was occurred in certified seed, which was followed by foundation seed. The minimum number of wilt infected plants 0.95 % were recorded from minituber (Fig. 20). The number of infected plants by bacterial wilt (*Ralstonia solanacearum*) were increased with advancing generation. The more generation number of potato ensure more time for soil contact of seed potato to infect by wilt.

The result is supported by the report of Anonymous. (2015) where stated that “the pathogen (*Ralstonia solanacearum*) is a seed and soil-borne bacterium that causes bacterial wilt disease. The latent (not visually observable) infections in seed potatoes allow the disease to spread unnoticed from one potato field to another and from one production region to another”. The results is also corroborated with the finding of Bekele (2017) where he stated that the local variety had significantly ($p<0.05$) higher 20.93% bacterial wilt incidence than the improved variety which had 3.98% whereas in the 4th cycle it increased by 75% and 50% respectively.

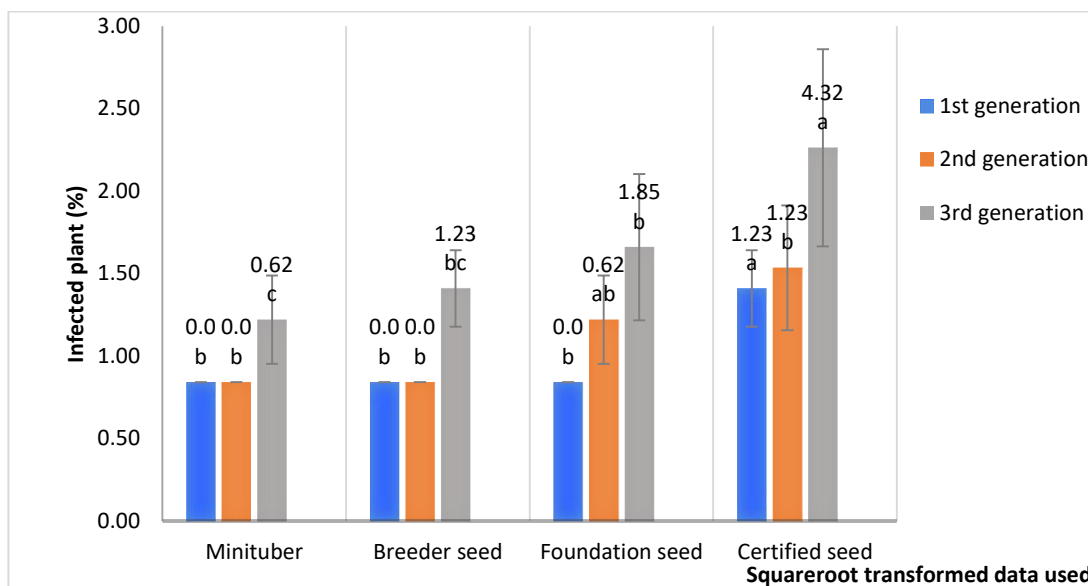


Fig. 20. Status of different categories of seed potatoes on wilt in advancing generation

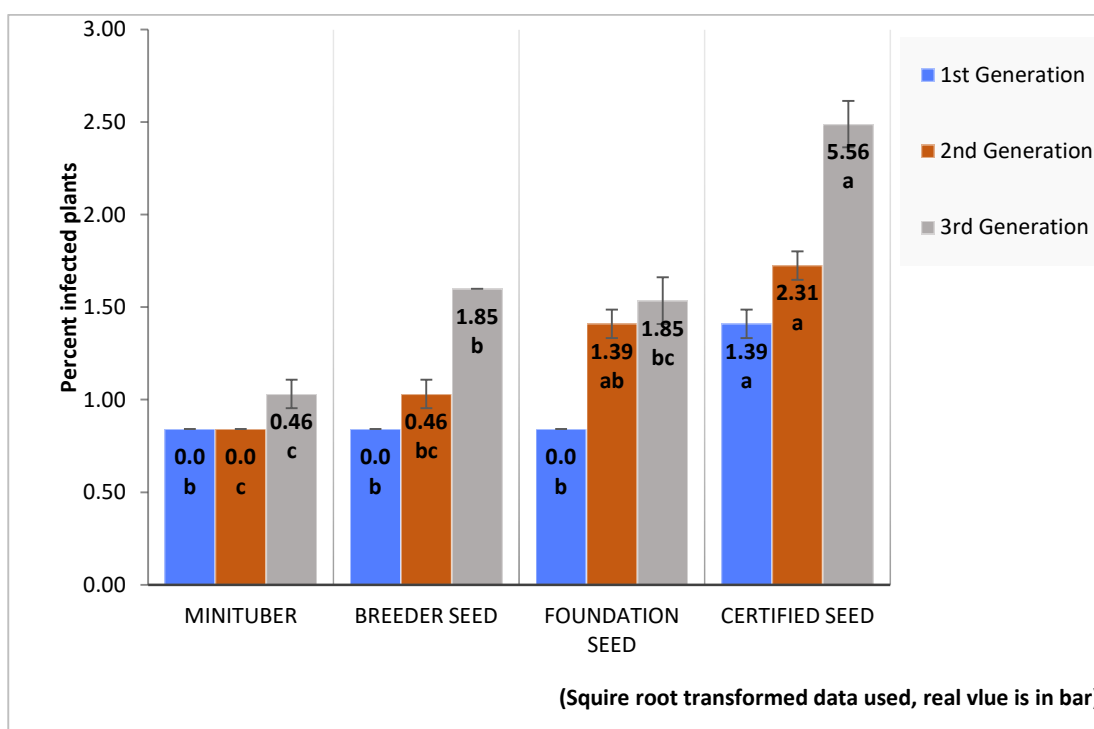


Fig. 21. PVY infection at different categories seed potato in advancing generation

4.4.11. Status of different categories of seed potato on potato virus Y in advancing generation

Effect of different categories seed potato in advancement to next two subsequent year on naturally developed potato virus Y (PVY) were differ significantly. There were no PVY infected plant counted from all categories of seed potatoes except certified seed (0.46 %) in 1st generation. In 2nd generation of different categories seed potatoes, significant variation was observed on PVY infected plant. The maximum (1.39%) PVY infected plants were counted from certified seed and minimum (0.0 %) PVY infected plants were counted from minituber and breeder seed. In 3rd generations of different categories seed potatoes were also differed significantly on infection of PVY. The highest percent (5.56 %) PVY infected plants were recorded from certified seed and lowest (0.46 %) percent infected plant was recorded from minituber. From the graph it revealed that PVY is increased with increase generation of seed potato (Fig 21). These results are corroborated with the results of Sarker *et al.*, (2017), Islam *et al.*, (2014), Ali *et al.*, (2013), Rahman and Akanda (2010), Rahman and Akanda (2009) and Bari *et al.*, (1998), where they opined that PVY infection is related with advancement of seed tuber generations.

4.4.12. Status of different categories of seed potato on potato leaf roll virus in advancing generation

Effect of different categories of seed potato in progression to next two subsequent generation on naturally infected potato leaf roll virus (PLRV) were differ significantly. In 1st generation, no PLRV infected plant was found from minituber and breeder seed. But the maximum 1.39 % PLRV infected plants were counted from certified seed.

In 2nd generation, the effect of different categories seed potatoes on PLRV infection was also varied significantly. The maximum (3.70 %) PLRV infected plants were counted from certified seed and the minimum (0.46%) infected plants were counted from minituber.

Similar variation was observed among the 3rd generation of different categories seed potato. The maximum (6.02%) PLRV infected plants were recorded from the certified seed and the minimum (1.85 %) was recorded from the minituber. From the graph it may revealed that PLRV is increased with increase generation of seed potato (Fig. 22).

Rahman and Akanda (2010), Rahman and Akanda (2009) and Bari *et al.*, (1998) also opined similar infection behavior of increasing PLRV on advancing generations of potato.

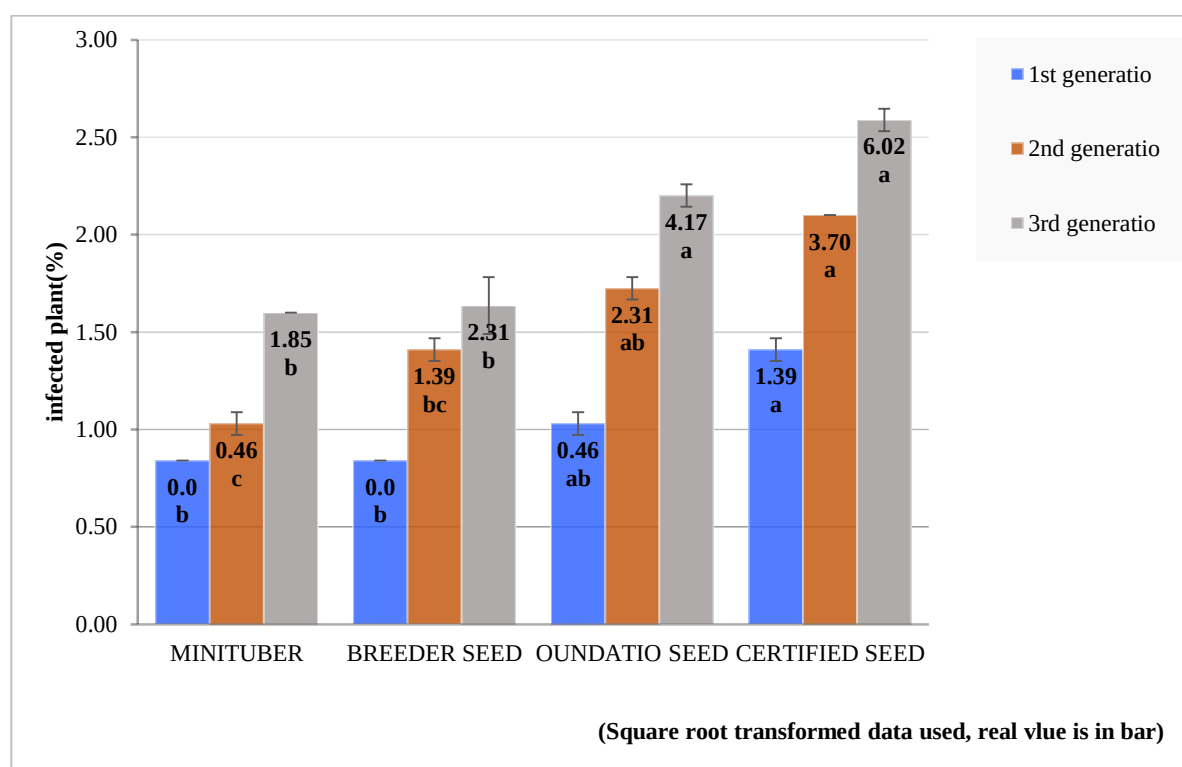


Fig. 22. PLRV infection at different categories seed potato in advancing generation

4.4.13. Tuber infection by *Rhizoctonia* canker on different categories of seed potato

In 1st generation, the tuber infection by *Rhizoctonia* canker of different categories of seed potatoes was varied significantly. The maximum 1.18% infected tubers were recorded from the certified seed and the minimum 0.30 % infected tubers were recorded from minituber (Table 26).

Similar trend of infection by *Rhizoctonia* canker was found in 2nd generation of different categories of seed potatoes. They were varied significantly and ranged from 4.38 to 7.87 %. The extreme tuber infections were counted from certified seed and least infected tubers were counted from minituber.

In 3rd generation, the infection by *Rhizoctonia solani* of different categories seed potatoes were varied significantly. The highest 21.9 % infected tubers were found from the generations of certified seed. The lowest 6.85 % infected tubers were found at minituber. From the table 4.1 it revealed that *Rhizoctonia* canker infection on tuber was increased with increasing generation of seed potato (Table 26). Infection of tuber by *Rhizoctonia* canker is increased with increasing generation and number of growing season may be due to transmission of pathogens by seed and soil. The results are corroborated with the findings of Kumar *et al.*, (2017), Tsror (Lahkim) *et al.*, (1999) and Slack (1993) where they stated that *Rhizoctonia solani* is soil and tuber borne disease. This result is dissimilar with the findings of Gundi *et al.*, (2011) where they observed that *Rhizoctonia* canker is not influenced by the generation of seed potato.

4.4.14. Status of different categories of seed potato on common scab in advancing generation

Effect of different categories seed potatoes on common scab of potato was differ significantly at next 2 subsequent generations. The highest infected tubers (2.32 %) were recorded from certified seed and the lowest (0.15 %) of infected tubers were found in minituber. The results revealed that use of infected seed influence the infection on progeny of tubers (Table 26). The result is supported by the findings of Rahman *et al.*, (2013) where they stated that increasing inoculum level in seed tuber caused increasing infection on progeny tubers and the number of russet, deformed and sclerotia bearing tubers were higher when 100% infected tubers were sown.

Table 26. Infection (%) of *Rhizoctonia* canker at different categories seed potato with advancing generation

Treatments	<i>Rhizoctonia</i> canker infected tubers (%)		
	1 st Generation	2 nd Generation	3 rd Generation
Minituber	0.32 (1.00) b	4.38 (2.02) b	6.85 (2.58) b
Breeder seed	0.30 (1.00) b	5.75 (2.36) ab	7.23 (2.58) b
Foundation seed	0.70 (1.18) ab	7.74 (2.73) a	15.05 (3.85) a
Certified seed	1.18 (1.37) a	7.87 (2.76) a	21.9 (4.65) a
LSD _{0.05}	0.20	0.54	0.88
CV%	10.74	13.69	16.07

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. (Square root transformed values are within the perimeter)

At 2nd and 3rd generation of seed potatoes common scab development had no variations among the different categories (Table 27). This results is supported by the results of Adams and Hide (1981) where they stated that scab incidence on progeny tubers was very slight and unrelated to the severity of disease on the seed tubers. Yield and quality of tuber is deteriorate due to introduction of seed born common scab, black scarf and brown rot pathogen in field in subsequent generation of potato was reported by Singh *et al.*, (2014).

4.4.15. Status of different categories of seed potatoes on deformed tuber in advancing generation

The effect of different categories seed potatoes on deformed seed tuber in advancing generation at three subsequent year was presented in Table 28. In 1st generation the deformed seed tubers had no significant variations among the different categories seed potatoes. But it ranged from 1.12% to 2.32. In 2nd generation of different categories of seed potatoes performed similar trends of deformed tubers and ranged from 1.97 % to 2.63 %.

Table 27. Infection (%) of common scab at different categories seed potato in advancing generation

Treatments	Common scab infected tubers (%)		
	1 st Generation	2 nd Generation	3 rd Generation
Minituber	0.15 (0.92) b	0.54 (0.61)	1.33 (1.32)
Breeder seed	0.78 (1.20) b	0.62 (0.78)	2.43 (1.67)
Foundation seed	1.02 (1.31) b	1.26 (1.11)	5.80 (2.50)
Certified seed	2.32 (1.74) a	1.64 (1.20)	6.75 (2.64)
LSD _{0.05}	0.24	0.76	1.72
CV%	11.7	36.88	37.73

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. (Square root transformed values are within the perimeter)

In 3rd generation, there was significant variation on developed deformed potato tubers among the different categories of seed potatoes. The maximum 9.03 % deformed tubers were counted from certified seed. The minimum 1.90 % deformed tubers were counted from minituber which was similar with breeder seed. From the table 3 it may concluded that deformed tubers were expanding with the increasing generation of seed potato (Table 28). These results were supported by the report of Gundi *et al.*, (2011) where they stated that the growth crack, discoloration, hollow heart were unbiased by the different generation of seed potato.

Table 28. Deformed tuber (%) at different categories seed potato with advance generation

Treatments	Deformed tuber (%)		
	1 st generation	2 nd generation	3 rd generation
Minituber	1.12 (1.28)	2.05 (1.40)	1.90 (1.55) c
Breeder seed	1.50 (1.37)	2.63 (1.59)	4.80 (2.31) b
Foundation seed	1.38 (1.34)	2.04 (1.38)	6.78 (2.68) ab
Certified seed	2.32 (1.57)	2.15 (1.39)	9.03 (3.12) a
LSD _{0.05}	0.33	0.28	0.67
CV%	33.83	27.57	17.44

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability. (Square root transformed values are within the perimeter)

4.4.16. Yield of different categories of seed potatoes in advancing generation

Yield (ton per hectare) was varied significantly among the different categories of seed potatoes. In 1st generation, the maximum yield (39.34 ton/ha) was found from foundation seed which was similar with breeder seed. The minimum yield (35.31 ton /ha) was found from minituber (Table 29). The yield of 2nd generation of different categories seed potatoes were not varied significantly. But the highest total tuber yield (39.46 ton /ha) and the lowest tuber yield (35.84 ton /ha) was found from progeny of minituber and certified seed, respectively.

In 3rd generation, the different categories seed potatoes was also statistically non-significant on yield, but it ranged from 33.20 ton/ha (certified seed) to 36.62 ton /ha (minituber). (Table 29). Minitubers were smaller than others. The smallest seed potato need closer spacing. But in this experiment, similar spacing were used for all categories seed potato. So the yield of minituber was lowest in 1st generation. The size of minituber in 2nd and 3rd generation was normal, but comparatively disease infestation was lower on seed tuber. For these reason yield of minituber was increased in next two subsequent generation.

These results were similar with the findings of Gunadi *et al.*, (2011). Ali *et al.*, (2013) Muthoni, Shimelis and Melis (2013) Ranalli *et al.*, (1994) Tien *et al.*, (1982), Sawicka (1994) and Bari *et al.*, (1998) where they stated that the yield decrease and infections increase with the increasing generations.

Table 29. Yield of different categories seed potato with advancing generation

Treatments	Total yield (ton/ha)		
	1 st generation	2 nd generation	3 rd generation
Minituber	35.31 b	39.46	36.62
Breeder seed	38.48 a	38.42	36.38
Foundation seed	39.34 a	37.57	35.68
Certified seed	37.96 ab	35.84	33.20
LSD _{0.05}	2.77	2.81	2.88
CV%	4.59	5.45	5.39

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.4.17. Healthy tuber yield of different categories of seed potatoes in advancing generation

The healthy tuber yield of different categories of seed potatoes was varied significantly in 1st, 2nd and 3rd generation. In 1st generation, the highest healthy tuber yield (36.58 ton/ha) was recorded from breeder seed which was similar with foundation seed (36.42 ton/ha). The lowest healthy tuber yield was recorded from certified seed (33.80 ton/ha). In 2nd generation, the highest healthy tuber (36.39 ton /ha) was found from progeny of minituber. The lowest healthy tuber yield (31.01 ton /ha) was found from progeny of certified seed. In 3rd generation, the maximum healthy tuber 32.85 ton/ha was produced from minituber which was similar with breeder seed. The minimum 16.91 ton/ha healthy tuber was produced from certified seed which is similar with foundation seed (Table 30). Minitubers were smaller than others. The smallest seed potato need closer spacing. But in this experiment, similar spacing were used for all categories seed potato. So the yield of minituber was lowest in 1st year. But the seed size of 1st and 2nd generation of minituber was normal and disease infestation was lower. For these reason yield of minituber was increased.

From the results, it was revealed that increasing generation of potato seed decrease the percent of healthy seed tuber production. These results were similar Gunadi *et al.*, (2011). Ali *et al.*, (2013) Muthoni, Shimelis and Melis (2013) Ranalli *et al.*, (1994) Tien *et al.*, (1982), Sawicka (1994) and Bari *et al.*, (1998) where they stated that the yield decrease and infections increase with the increasing generations.

Table 30. Healthy tuber yield of different categories seed potato with advancing generation

Treatments	Healthy Tuber yield (ton/ha)		
	1 st generation	2 nd generation	3 rd generation
Minituber	34.00 b	36.39 a	32.85 a
Breeder seed	36.58 a	34.86 ab	30.02 a
Foundation seed	36.42 a	32.92 bc	21.56 b
Certified seed	33.80 b	31.01 c	16.91 b
LSD _{0.05}	2.38	2.40	5.25
CV%	4.22	4.44	12.95

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.4.18. Percentage yield increased or decreased by advancing the generation of different categories seed potato

Advancing generation of different categories of seed potatoes effect on the tuber yield. Considering the 2nd generation of different categories of seed potatoes, the maximum 12.08% tuber yield was increased from minituber. The yield decreased 5.64% from certified seed and 4.58% from foundation seed. In 3rd generation of different categories of seed potatoes, the maximum 3.95% tuber yield was increased from minituber. The yield decreased 12.53% from certified seed, 9.11% from foundation seed and 5.23% from breeder seed (Fig 23).

The increasing the generation decrease the yield of potato. Yield was reduced with increasing generations by using resting seeds of similar stock was reported by Rahman and Akanda (2010), Rahman and Akanda (2009) Hussain *et al.*, (1978). On an average 27-40% yield loss of potato in the subsequent year was observed by Ghimire *et al.*, (2016).

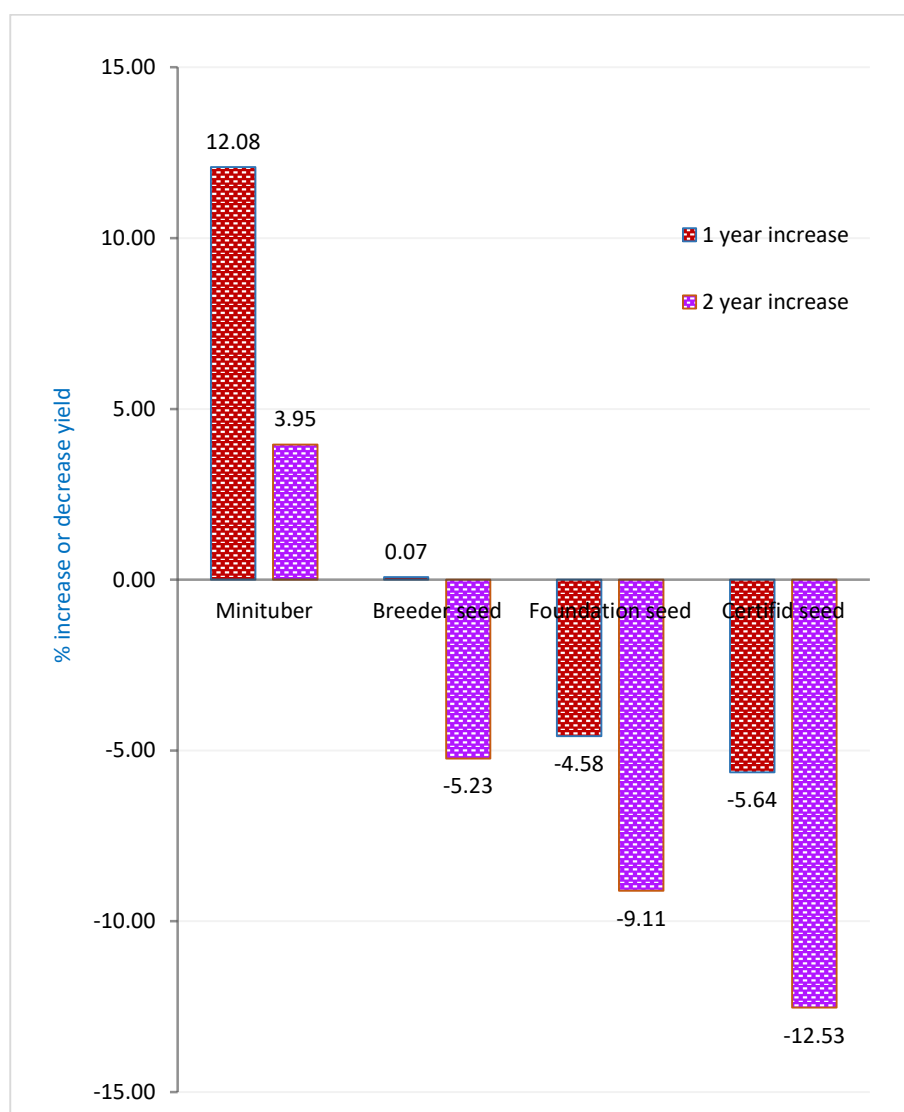


Fig 23. Yield increased or decreased by advancing the generation of potato

4.4.19. Increase or decrease percentage of healthy tuber yield from advancing generation of different categories seed potato

Among the different categories of seed potato of 2nd generation, only 7.06% healthy tuber yield increased by minituber. On the other hand, the highest 9.62 % and 8.33 % healthy tuber yield was decreased from foundation seed and certified seed, respectively (Fig 24).

In 3rd generation. 45.77% and 34.56% healthy tuber yield was decreased from certified seed and foundation seed. minituber decrease 7.46% healthy tuber yield (Fig 24). The increasing the generation decrease the healthy tuber yield of potato and the decreasing percent is influenced by the seed quality.

These results were similar Ali *et al.*, (2013) Muthoni, Shimelis and Melis (2013), Gunadi *et al.*, (2011), Rahman and Akanda (2010), Rahman and Akanda (2009), Ranalli *et al.*, (1994), Tien *et al.*, (1982), Sawicka (1994) and Bari *et al.*, (1998) where they stated that the yield decrease stated that tuber yield was reduced with increasing generations by using resting seeds of similar stock.

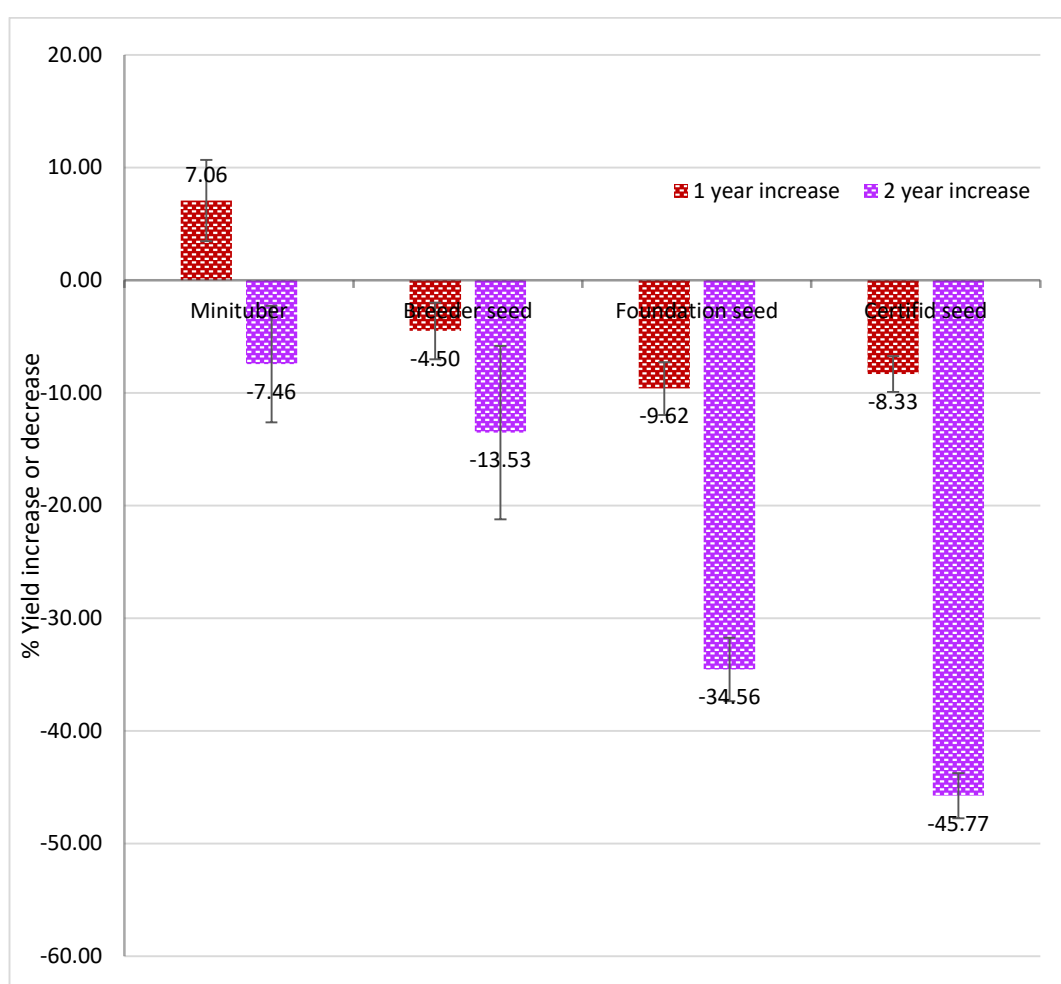


Fig 24. Healthy tuber yield increased or decreased by advancing the generation of potato

Experiment 5. **Effect of haulm pulling and seed size on GA₃ treated seed potato**

The experiment was conducted in 2017-18 at research field of HSTU and the results on the different parameter have been presented in this chapter.

4.5.1. Influence of different haulm pulling times on growth of potato

The GA₃ treated seed potatoes manifested significant variation in respect of plant height and leaf area coverage (%) at different haulm pulling (HP) times. The highest plant height (61.2 cm) was recorded from the haulm pulling time of 89 days after planting (DAP), which was statistically similar with the HP time of 96 DAP. The lowest plant height (56.1 cm) was observed from the HP time at 103 DAP. The stem number per hill was not varied significantly. But the maximum stem number per hill (11.1) was observed from the haulm pulling time of 89 DAP which and the lowest stem number per hill (9.5) was from the haulm pulling time of 103 DAP. The highest LAC (91.3%) was found from the haulm pulling time at 75 DAP which was similar with the haulm pulling time of 82 / 89 DAP. The lowest LAC (93.50%) was found from GA₃ treated plot at the haulm pulling time of 103 DAP (Figure 25). The GA₃ treated seed potatoes performed more LAC due to maximizing stem number per hill and maximizing plant height by cell division and elongation of plants. The result is supported by the findings of Prasad *et al.* (2013), Alexopoulos *et al.* (2006), Loretta and Mikitzel (1993) and Virtanen *et al.*, (2013); where they stated that application of GA₃ significantly increased plant height and there was a linear increase in growth parameters like plant height, stem numbers per hill.

4.5.2. Effect of haulm pilling time of GA₃ treated seed potato on field diseases

The effect of different haulm pulling time on the naturally occurred potato mosaic virus (PMV), potato virus Y(PVY) potato leaf roll virus (PRLV) and black scurf was varied significantly (Table 2). The maximum infected plants ((PMV 3.70%, PVY 2.78 % and PRLV 4.32 %,) were recorded from late haulm pulling (103 DAP) and the minimum infected plants (PMV 0.62 %, PVY 0.31 % and PRLV 0.95 %) were recorded from haulm pulling (75 DAP with GA₃) (Table 31). The incidence of Black scurf of potato plants varied significantly in different haulm pulling time. The highest (1.85 %) Black scurf (*Rhizoctonia* canker) infected plant was found from the haulm pulling time at 103 DAP, which was similar with the date of haulm pulling at 96 DAP (Table 31). Delaying haulm pulling time increase the infection percentage of different diseases. These results are agreement with the finding of Monsor (2014), where he stated that late haulm pulling of seed potato plant increase the percentage virus infected plants.

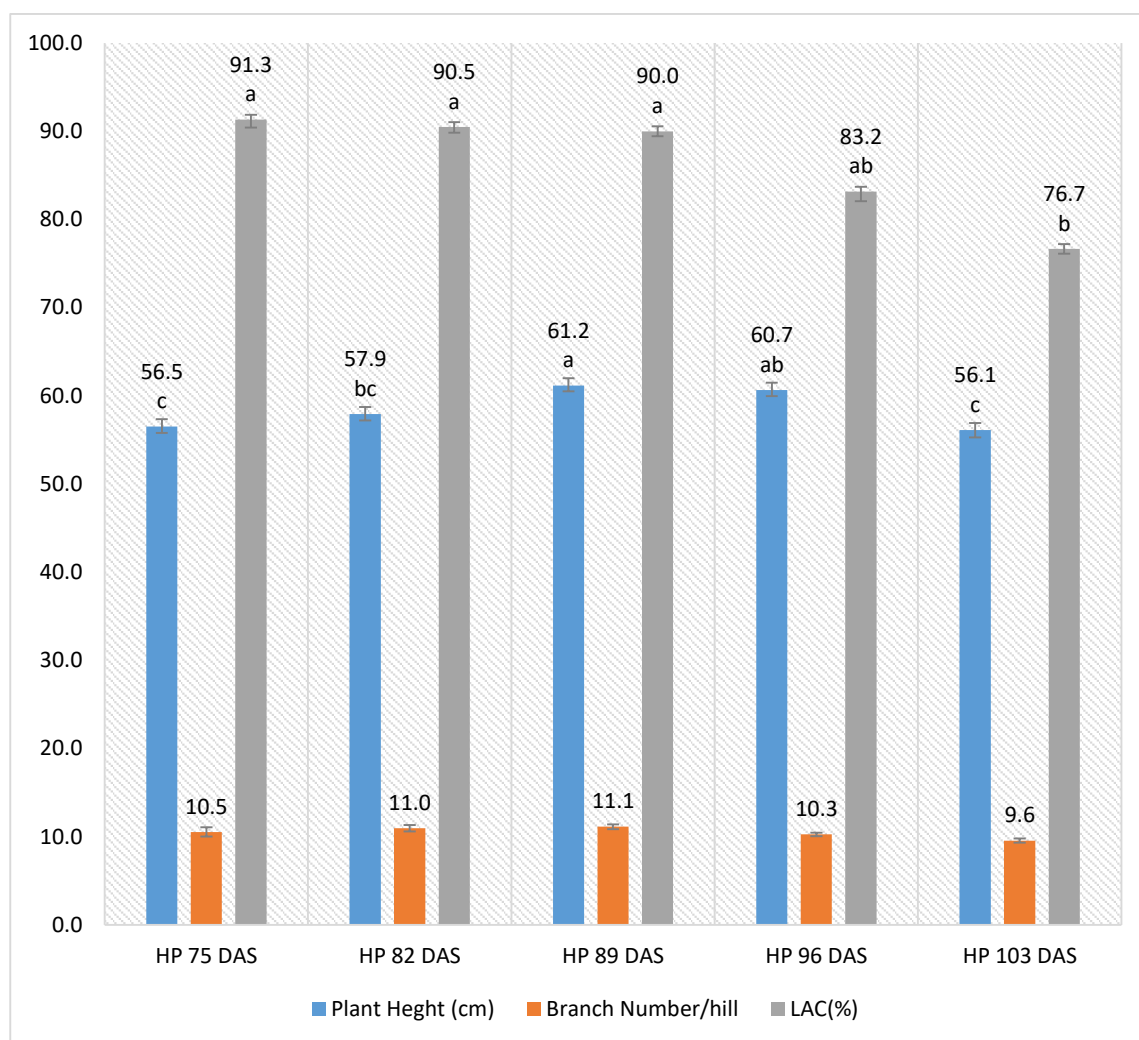


Fig 25. Effect of haulm pulling times on vegetative growth of potato where GA₃ treated potato tuber was used

Table 31. Effect of haulm pilling time of GA₃ treated seed potato on field diseases

Haulm Pulling Time	PMV	PVY	PLRV	Black Scurf
75 DAP	0.62 (1.09) b	0.31 (0.97) c	0.95 (1.20) c	0.00 (0.84) c
82 DAP	1.23 (1.30) b	0.62 (1.09) bc	1.55 (1.37) bc	0.31 (0.97) bc
89 DAP	1.85 (1.56)ab	0.62 (1.09) bc	2.18 (1.63) abc	0.92 (1.22) ab
96 DAP	3.08 (1.87)a	1.54 (1.47) ab	3.12 (1.92) ab	1.54 (1.43) a
103 DAP	3.70 (2.02)a	2.78 (1.85) a	4.32 (2.22) a	1.85 (1.56) a
LSD _{0.05}	0.54	0.45	0.62	0.36
CV%	28.14	28.42	30.57	24.71

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

Figures in parenthesis indicate transformed value

4.5.3. Effect of different haulm pulling time on production of different grade seed potato number

The number of different categories of potato per plant produced from GA₃ treated MST was varied significantly by different haulm pilling time. (Table-32). The maximum tuber number per plant (16.20) of smallest (10- 28 mm) tuber was recorded from haulm pilling time of 89 DAP which was similar with the haulm pulling time of 96, 103, 82 DAP. The highest number (7.47) of 28-40 mm size (“A”-grade) seed tuber was observed from the haulm pilling time 96 DAP. The minimum (4.73) number of 28 - 40 mm (“A” Grade) tuber was recorded from the haulm pilling time 75 DAP. The largest number (2.70) of 40 - 55mm (“B” Grade) tuber per plat was counted from haulm pilling time of 103 DAP. The minimum number (0.90) of “B” grade seed tuber was recorded from haulm pilling time of 75 DAP. There was no oversize tuber produced from the haulm pilling time at 75 and 82 DAP, but highest number (0.20) of oversize tuber found from the haulm pilling time at 96 DAP. From the result it is revealed that the mass increasing of potato tuber was continued upto 89 DAP; and increase the haulm pulling time increase the number of different graded seed potato except below size seed tuber. Similar results was observed by Alam *et al.* (2017), Monsor (2014)^b who reported that harvesting dates influenced number of tuber per hill.

Table 32: Effect of haulm pilling time on production of different categories seed potato number per plant

Treatments	Number of tuber per plant			
	10-28 mm	28-40 mm	40-55 mm	> 55 mm
75 DAP	9.67 ab	4.63 b	0.90 c	0.00 b
82 DAP	14.00 a	5.80 ab	1.53 bc	0.00 b
89 DAP	16.20 a	7.03 ab	2.07 ab	0.13 a
96 DAP	14.53 a	7.47 a	2.47 ab	0.20 a
103 DAP	14.50 a	7.07 ab	2.70 a	0.17 a
LSD _{0.05}	7.32	0.94	1.03	0.14
CV%	32.51	22.3	29.32	93.24

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.5.4. Effect of seed tuber size on production of different categories seed tuber number

The GA₃ treated 35- 45 mm and 45- 55 mm mother seed potato produced non-significant number of different size tuber per plant, but “A” grade (28 to 40 mm) tuber per plant. The highest number (6.61) of “A” grade tuber per plant was produced by largest size seed tuber (45 to 55 mm). The lowest number (5.63) of “A” grade seed tuber was counted from the 35 to 45 mm mother seed potato (Table 33). Seed tuber size significantly affected the “A” grade seed potatoes per plant. The result is supported by the findings of Gulluoglu and Arioglu (2009) and Michael, *et al.*, (2012); where they reported that tuber yields per hectare consistently increased with increasing seed size and bigger seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites.

Table 33: Effect of mother seed tuber size on production of different categories seed tuber number per plant

Treatments	The number of tuber per plant			
	10-28 mm	28-40 mm	40-55 mm	>55 mm
35- 45 mm	11.23	5.63 b	2.07	0.12
45- 55 mm	13.81	6.61 a	1.87	0.06
LSD _{0.05}	12.09	4.06	1.714	0.25
CV%	32.51	22.3	29.32	93.24

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.5.5. Influence of haulm pulling times where GA₃ treated mother seed tuber was used on production of different categories seed tuber weight

The different haulm pulling times influenced the weight of different tuber size per plant was varied significantly (Table 34). The highest weight (117.43 g) of 10-28 mm sized seed tuber was counted from 89 DAP which was similar with 82 and 103 DAP. The lowest weight (44.13 g) of seed tubers was recorded from control (without GA₃ treated mother seed tuber and HP at 75 DAP).

Maximum weight (45.65 g) of 28-40 mm tubers per plant was recorded from the haulm pulling time of 89 DAP, which was similar with 96 DAP. The lowest of weight (139.50 g) of 28 - 40 mm tubers per plant was collected from the control. The highest weight (219.67 g) and the lowest weight (71.50 g) of 40-55 mm tuber per plant was counted from the haulm pulling time of 103 DAP and 75 DAP respectively. The greater (29.1 g) number of over size tuber per plant was counted from 103 DAP and minimum from 75 or 82 DAP (Table 34).

Table 34: Effect of haulm pilling time on production of different categories seed tuber (weight per plant) where GA₃ treated mother tuber were used

Treatments	Tuber weight per plant (g)			
	10-28mm	28-40mm	40-55mm	> 55mm
75 DAP	89.63ab	162.23 bc	71.50 c	0 b
82 DAP	116.2 a	215.40 ab	123.67 bc	0 b
89 DAP	117.43a	246.00 a	157.33 abc	21.73 a
96 DAP	107.83ab	251.50 a	187.67ab	30.27 a
103DAP	116.27 a	216.93 ab	219.67a	29.10 a
LSD _{0.05}	27.46	72.99	88.34	33.60
CV%	40.3	19.77	32.98	92.97

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.5.6. Effect of mother seed tuber size on production of different categories seed tuber weight

The GA₃ treated 35 to 45 mm and 45 to 55 mm mother seed tuber performed significant variation on the weight of 10-28 mm and 28-40 mm size tuber per plant. The highest weight (113.51 g) of 10 – 28 mm tuber per plant was counted from the 45 – 55 mm size mother seed tuber and the highest weight (22.03 g) of “A” grade (28 to 40 mm) tuber per plat was counted from 45-55 mm mother seed (Table 35).

Table 35: Effect of mother seed tuber size on production of different categories seed tuber weight per plant

Treatments	Tuber weight per plant (g)			
	10-28mm	28-40mm	40-55mm	> 55mm
35- 45 mm	83.66 b	188.49 b	158.53	20.09
45- 55 mm	113.51 a	222.03 a	139.36	8.33
LSD _{0.05}	117.99	120.54	145.88	39.24
CV%	40.3	19.77	32.98	92.97

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

The mother seed tuber size has positive effect in smallest “A” grade and below size potato weight per plant. The result is corroborated with the findings of Gulluoglu and Arioglu (2009) and Michael, *et al.*, (2012) where they reported that tuber yields per hectare consistently increased with increasing seed size and bigger seed potato tubers exhibited greater overall resource use efficiency of allocation of metabolites.

4.5.7. Influence of different haulm pulling time where GA₃ treated mother seed tuber were used on yield and yield component of potato

The different haulm pulling times of potato affected tuber number per plant was varied significantly (Table-36). The maximum number of total tuber per plant (25.43) was counted from haulm pulling time of 89 DAP which was similar with the haulm pulling time of 96 or 103 DAP. The lowest number (15.20) of total tuber number per plant was found from the haulm pulling time of 75 DAP. The maximum number (9.93) of seed tubers per plant was recorded from the haulm pulling time of 96 DAP, which was similar with the haulm pulling time of 103 DAP. The lowest number of seed tubers per plant (5.53) was collected from HP at 75 DAP (Table 36). The potato tuber size was increased upto 89 DAP due to hormone application and increase the haulm pulling time increase the food accumulation of potato and increase size of tuber. Similar results was observed by Alam *et al.* (2017), Monsor (2014)^b who reported that harvesting dates influenced number of tuber per hill.

The different haulm pulling times significantly influenced the tuber weight per plant, seed tuber weight per plant, yield and seed yield of potato (Table 36). On the basis of total tuber weight per plant, the highest tuber weight (581.97g) per plant was recorded from the haulm pulling time of 103 DAP, which was similar with the haulm pulling time of 89 or 96 DAP. The lowest total tuber weight (323.37 g) was recorded from the haulm pulling time of 75 DAP. The maximum weight (439.17 g) of total seed tuber per plant was recorded from the haulm pulling time at 96 DAP, which was statistically similar with 89 and 103 DAP. The minimum weight (233.73 g) of seed tuber per plant was observed in the 75 DAP haulm pulling.

The similar significant trend also observed in yield of potato. The maximum potato yield (38.8 ton/ha) was recorded from 103 DAP haulm killing which was similar with the haulm pulling time of 89 and 96 DAP. The lowest yield (21.56 ton /ha) was recorded from the haulm pulling time of 75 DAP (Table 36). Similarly, the maximum seed potato yield (29.28 ton/ha) was recorded from 96 DAP haulm killing which was with 89 and 103 DAP haulm killing. The lowest yield (15.58 ton /ha) was recorded from 75 DAP haulm pulling.

The potato (variety cardinal) was matured after 75 DAP and complete it's tuber mass under soil. But using GA₃ at seed potato may increase the time of vegetative growth of potato. So the tuber weight per plant and yield were higher after 82 to 96 DAP (Table 36). Similar results was observed by Alam *et al.* (2017), Afsana (2018) and Monsor (2014) who reported that harvesting dates influenced weight of tuber per hill.

Table 36. Effect of different haulm pulling time on yield and yield component of potato

Treatments	Tubers /plant	Seed Tubers /plant	Tuber weight /plant(g)	Seed weight /plant(g)	Yield (ton/ha)	Seed yield (ton/ha)
75 DAP	15.20 b	5.53 c	323.37 b	233.73 b	21.56 b	15.58 b
82 DAP	21.33ab	7.33abc	455.27 ab	339.07 ab	30.35 ab	22.61 ab
89 DAP	25.43 a	9.10 ab	542.5 a	403.33 a	36.17 a	26.89 a
96 DAP	24.67 a	9.93 a	577.27 a	439.17 a	38.48 a	29.28 a
103DAP	24.43 a	9.77 a	581.97 a	436.60 a	38.8 a	29.11 a
LSD _{0.05}	8.75	2.67	147.97	121.84	9.87	8.12
CV%	23.5	18.38	17.62	19.13	17.62	19.13

Figures in a column having similar letter(s) do not differ significantly at 5% level of probability.

4.5.8. Influence of GA₃ treated mother seed tuber size on the number of tuber per plant

The 35 to 45 mm and 45 to 55 mm mother seed potato (GA₃ treated) tuber size was not affect significantly on the number of tuber per plant. But, the largest seed tuber produced maximum number tuber per plant (Table 37).

The 35 to 45 mm and 45 to 55 mm mother seed potato (GA₃ treated) tuber size had no effect on the weight of tuber per plant, weight of seed tuber per plant, yield and seed yield of potato. But, the largest seed tuber produced maximum weight of tuber per plant, weight of seed tuber per plant, yield and seed yield of potato (Table 37).

Though, seed tuber size positively influence the tuber number and weight per plant, but application of GA₃ in seed tuber enhance the growth and development of plant and tuber. For these reason, the result is differ with the findings of Gulluoglu and Arioglu (2009), and Michael *et al.*, (2012) where they reported that tuber yields per hectare consistently increased with increasing seed size.

Table 37. Effect of different mother seed tuber size on yield and yield component of potato

Treatments	Tubers /plant	Seed Tubers /plant	Tuber weight /plant(g)	Seed weight /plant(g)	Yield (ton/ha)	Seed yield (ton/ha)
35- 45 mm	7.7	19.06	450.77	347.02	347.02	23.13
45- 55 mm	8.48	22.34	483.23	361.39	361.39	24.09
LSD _z	4.42	14.46	244.36	16.29	201.21	13.42
CV%	18.38	23.5	17.62	17.62	19.13	19.13

The statistical difference was found among the different haulm pulling time on *Rhizoctonia* canker of harvested tuber and seed tuber. The maximum infection (18.61) percentage of *Rhizoctonia* canker of potato was counted from the haulm pulling time at 103 DAP and the minimum infection (6.47) percentage was at the field of haulm pulling time at 82 DAP. The maximum infection (23.65) percentage of *Rhizoctonia* canker of seed potato was counted from the haulm pulling time at 103 DAP and the minimum infection (7.29) percentage of seed potato was recorded from the haulm pulling time at 75 DAP (Fig. 26). The damage is caused by *Rhizoctonia* canker is for temperature and environment. For *Rhizoctonia* canker, suitable temperature is as below 10° C and above 24° C (A. Mulder and L. J. Turkensteen. 2005) Moreover, Development of these diseases is favored by soil temperatures between 16 to 23 °C, while soil temperatures above 25°C reduce the severity of canker (Anderson. 1982). Green-crop-harvesting (harvesting the immature crop mechanically and returning the tubers to the soil for curing before final harvesting two to four weeks later) and immature-crop-harvesting (pulling haulms and collecting the tubers by hand) often result in low levels of black scurf (Mulder *et al.*, 1992; Lootsma & Scholte, 1996). This is also supported by Kumar *et al.*, (2017).

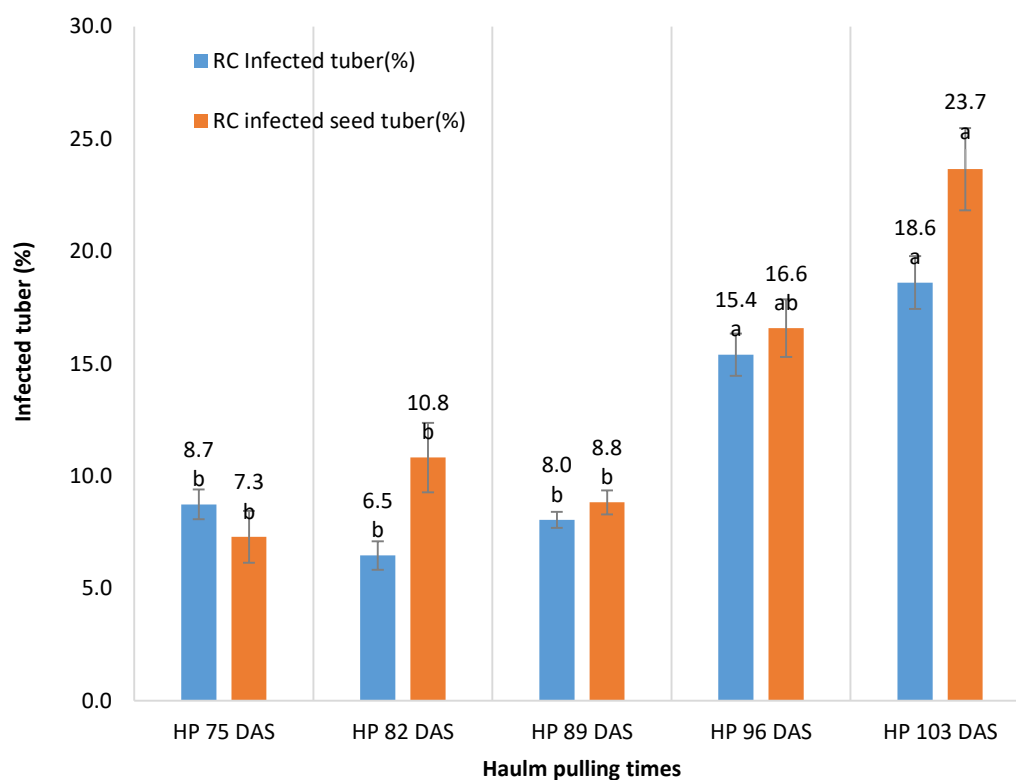


Fig. 26. Effect of different haulm pulling time on *Rhizoctonia* canker on potato tuber

4.5.9. Correlations among different plant growth parameters, diseases, yield components and yield in plots of GA₃ treated mother seed potato size and haulm pulling time

Plant height at haulm pulling time was positively correlated with stem number per hill at haulm pulling time, and PMV. The stem number per hill at haulm pulling time, is positively correlated with *Rhizoctonia* canker in potato (%). The Leaf area coverage (LAC) at haulm pulling time is negatively correlated with potato mosaic virus, potato virus Y, potato leaf roll virus, Black scurf (*Rhizoctonia* canker), *Rhizoctonia* canker in potato (%), *Rhizoctonia* canker in seed potato (%), number of seed tuber per plant, total tuber number per plant, Sdwt/pl (total seed tuber weight per plant (g)), tuber yield (ton/ha) and Seed tuber yield (ton/ha). Potato mosaic virus is positively correlated with potato virus Y, potato leaf roll virus, black scurf, number of seed tuber per plant, total tuber number per plant, total seed tuber weight per plant (g), tuber yield (ton/ha) and seed tuber yield (ton/ha). Potato virus Y is positively correlated with potato leaf roll virus, black scurf, *Rhizoctonia* canker in potato (%), number of seed tuber per plant, total tuber number per plant, total seed tuber weight per plant (g), tuber yield (ton/ha) and seed tuber yield (ton/ha). Potato leaf roll Virus is positively correlated with black scurf, *Rhizoctonia* canker in potato (%), number of seed tuber per plant, total tuber number per plant, total seed tuber weight per plant (g), tuber yield (ton/ha) and seed tuber yield (ton/ha). black scurf (*Rhizoctonia* canker) is positively correlated with number of seed tuber per plant, total tuber number per plant, total seed tuber weight per plant (g) and tuber yield (ton/ha). Number of seed tuber per plant, is positively correlated with total tuber number per plant, total seed tuber weight per plant (g), tuber yield (ton/ha) and seed tuber yield (ton/ha). Total tuber number per plant is positively correlated with total seed tuber weight per plant (g), tuber yield (ton/ha) and seed tuber yield (ton/ha). Total seed tuber weight per plant (g) is positively correlated with tuber yield (ton/ha) and seed tuber yield (ton/ha). Tuber yield (ton/ha) is positively correlated with seed tuber yield (ton/ha) (Table 38).

Table 38. Correlation coefficients among different plant growth, diseases, yield components and yield in plots of GA₃ treated mother seed potato size and haulm pulling time

	PH	BN	LAC	PMV	PVY	PLRV	BS	RCp	RCsp	Sd/pl	To No	To. Wt. g.	Sdwt/pl	Yield	Sd.Y
PH	1	0.41*	0.31	0.46**	0.05	0.19	0.25	-0.20	-0.29	0.06	0.11	0.17	0.17	0.17	0.1723
BN		1	0.32	0.14	-0.32	-0.19	0.09	-0.34*	-0.22	-0.04	0.18	-0.01	-0.09	-0.01	-0.10
LAC			1	-0.41*	-0.56**	-0.57**	-0.48**	-0.60**	-0.55**	-0.49**	-0.26	-0.39*	-0.42*	-0.39*	-0.42*
PMV				1	0.60**	0.48**	0.71**	0.29	0.22	0.38*	0.40*	0.43**	0.36*	0.43**	0.36*
PVY					1	0.65**	0.51**	0.49**	0.36	0.43**	0.38*	0.51**	0.45**	0.51**	0.45**
PLRV						1	0.42*	0.38*	0.25	0.60**	0.37*	0.59**	0.62**	0.59**	0.62**
BS							1	0.34	0.34	0.48**	0.60**	0.45**	0.32	0.45**	0.31
RCp								1	0.84**	0.29	0.17	0.26	0.21	0.26	0.21
RCsp									1	0.35	0.32	0.30	0.22	0.30	0.22
Sd/pl										1	0.78**	0.91**	0.88**	0.91**	0.88**
ToNo											1	0.79**	0.57**	0.79***	0.57**
toWt.g.												1	0.94**	1**	0.94**
Sdwt/pl													1	0.94**	1**
Yield														1	0.94**
Sd.Y															1

Correlation coefficients noted by Where, PH = Plant Height at haulm pulling time, BN = Branch Number at haulm pulling time, LAC = Leaf Area Coverage at haulm pulling time, PMV = Potato Mosaik Virus, PVY = Potato Virus Y, PLRV = Potato leaf roll Virus, BS= Black scurf (*Rhizoctonia* Canker), RCp = *Rhizoctonia* Canker in potato (%), RCsp = *Rhizoctonia* Canker in seed potato (%), Sd/pl = Number of seed tuber per plant, ToNo = Total tuber number per plant, toWt.g. = Total tuber weight per plant (g), Sdwt/pl = Total seed tuber weight per plant (g), Yield = tuber yield (ton/ha) and Sd. Y = Seed tuber yield (ton/ha).

4.5.10. Economic analysis

Variation in cost of production was noticed due to the cost of seed tuber and different haulm pulling time (Table 39). The total cost of cultivation ranged between 234960 and 311690 Tk./ha. The cultivation cost increased with increasing seed tuber size and Haulm pulling time.

The highest cost of production was involved when used 45 -55 mm size seed tuber and extra time of haulm pulling. The lowest cost of production was involved when used 35-45 mm size seed tuber with short time haulm pulling.

The highest gross return was obtained from the treatment combination 45-55mm mother seed with haulm pulling at 103DAP (702220 Tk. /ha) that was apparently similar to the treatment combination 35-45mm mother seed with haulm pulling at 96 DAP (672660 Tk./ha) and the lowest gross return (351530 Tk. /ha) was found from the treatment of 35- 45 mm with haulm pulling at 75 DAP (Table 39). However, the highest net profit (434700 Tk. /ha) was obtained from the treatment combination of 35 – 45 mm mother seed with haulm pulling at 96 DAP that was apparently similar (390530 Tk. /ha) to the treatment combination of 45 – 55 mm mother seed with haulm pulling at 103 DAP.

The maximum benefit-cost ratio was observed in of 35 – 45 mm mother seed with haulm pulling at 96 DAP (2.83). The lowest net profit and benefit-cost ratio (1.15) was observed in the treatment combination of 45-55 mm mother seed tuber with haulm pulling at 75 DAP. For economic point of view, results indicated that 35 – 45 mm mother seed with haulm pulling at 96 DAP was more profitable than the other treatment combination.

Table 39: Cost and return analysis in seed potato production as influenced by using GA₃ on mother seed tuber during 2017-18

Treatment	Prod. Cost (Tk)	Gross return (Tk)	Net Return (Tk)	BCR
35-45mm+75 DAP	234960	351530	116570	1.50
35-45mm+82 DAP	235960	485940	249980	2.06
35-45mm+89 DAP	236960	611060	374100	2.58
35-45mm+96 DAP	237960	672660	434700	2.83
35-45mm+103 DAP	238960	597710	358750	2.50
45-55mm+75 DAP	307690	355320	47630	1.15
45-55mm+82 DAP	308690	526690	218000	1.71
45-55mm+89 DAP	309690	594460	284770	1.92
45-55mm+96 DAP	310690	627280	316590	2.02
45-55mm+103 DAP	311690	702220	390530	2.25

CHAPTER 5

SUMMARY

Potato growers are usually use farm saved seed, which quality should be justified by comparing with certified seed, positive selection seed, seed plot technique's seed and TLS seeds potato. The maximum number of tuber per plant was recorded from Positive Selection's Seeds which is statistically similar with Certified Seed and seeds of seed plot technique's (STP). The maximum yield (27.72 ton/ha) was recorded from Positive Selection's Seeds which was similar with Certified and Seeds of SPT and the smallest weight (21.97 ton/ha) was observed in farmer's seed. Moreover, the maximum plants ($\geq 8\%$, 7.33 % and 4.17 %) were infected by PVY, PLRV and PMV respectively in Farmer's seed, but comparatively lower infected plants was found in the seed potatoes of certified and Positive selection.

The different seed planting times of 14th October, 4th November, 24th November and 14th December and different Haulm pulling times at 68, 75, 82 and 89 DAP were evaluated in the 2nd experiment for quality seed tuber production of Cardinal in Dinajpur region. At 30 DAP, 100% emergence was recorded from all planting time except 15 October. Maximum late blight infestation (2.90%) and LB severity i.e. PDI (21.81) was recorded in planting time of 24th November during 1st week of January 2017. At 60 DAP, maximum potato virus Y infected plants (2.08%) were identified from 24th November planting time which was followed by 4th November. At haulm pulling time, the highest percentage (9.38%) of PMV affected plants was counted from 24 November which was followed by 14th December. The maximum infected plants ((PRLV 3.13%, PMV 4.69% and PVY 2.6 %) were recorded from late haulm pulling (89/82 DAP) and the minimum infected plants ((PRLV 1.56%, and PVY 0 %) were recorded from early haulm pulling (68 DAP). The maximum potato yield (29.23 ton/ha) was recorded from 24 November with HP 89 DAP and the lowest yield (12.26 ton /ha) was recorded from 14 October with HP 68 DAP. The maximum seed potato yield (23.87 ton/ha) was recorded from 4 November with 82 DAP. The lowest seed potato yield (1083 ton /ha) was recorded from 14 October with HP 89 DAP.

The 3rd experiment was conducted at the research field and post graduate laboratory of Plant Pathology Department, HSTU, Dinajpur, during November 2016 to march 2017 using potato variety Cardinal. The different size of mother seed tuber like $S_1 = 15$ to 25 mm, $S_2 = 25$ to 35

mm, $S_3 = 35$ to 45 mm and $S_4 = 45$ to 55 mm diameter was considered as factor A and different concentration of GA_3 like $G_{00} = 00$ ppm, $G_{20} = 20$ ppm, $G_{40} = 40$ ppm, $G_{60} = 60$ ppm for treatment of mother seed tuber was considered as factor B. The highest (23.05) and lowest (6.933) branch number of sprouts /tuber were recorded from S_4 and S_1 respectively. The highest (17.90) and lowest (14.56) branch number of sprouts /tuber was recorded from G_{40} . And G_{00} , respectively. At 65 DAP, the maximum and minimum PDI of late blight 1.05 and 1.25 were recorded from S_1 and S_4 respectively. Similarly, the maximum and minimum PDI of late blight was recorded from G_{40} and G_{60} respectively. Similarly, the maximum percentage of potato mosaic virus and potato leaf roll virus was found at G_{60} and minimum was found at G_{20} . The maximum and minimum percentage of potato leaf roll virus was found in S_1 and S_4 . The highest tuber number per plant (23.24 and 22.28) was recorded from S_4 and G_{60} respectively. The lowest number of tuber per plant (12.43 and 12.33) was produced from small of S_1 and G_{00} . The height and lowest yield (42.67 ton/ha and 18.47 ton/ha) was recorded from S_4G_{60} and S_1G_{00} , respectively.

The 4th experiment was conducted at research field of HSTU, Dinajpur, during winter 2014-15, 2015-16 and 2016-17 cropping seasons. The four different categories of seed potato viz. Minituber, breeder seed, foundation seed, and certified seed were used in the experiment. In 1st, 2nd and 3rd generation, the maximum 0.46 %, 1.39 % and 5.56% plants were naturally infected by potato virus Y in certified seeds. The minimum 0%, 0% and 0.46% plants were naturally infected by potato virus Y in minituber. Similar results were recorded for PLRV. The infestation of *Rhizoctonia* canker, common scab and deformed tuber of potato were also increased with increasing generation. In 1st generation, the highest healthy tuber yield (36.58 ton/ha) was recorded from breeder seed. In 2nd and 3rd generation, the highest healthy tuber (36.39 ton /ha and 32.85 ton/ha) was found from progeny of minituber. The lowest healthy tuber yield was recorded from certified seed (33.80, 31.01 and 16.91 ton/ha) was found from 1st, 2nd and 3rd generation of certified seed. But increasing generation decrease the healthy tuber yield except minituer (7.06% in 2nd generation).

The last experiment was conducted to determine appropriate haulm pulling time in seed potato production when the seed potatoes were treated with GA_3 . The treatments was as 35 to 45 mm and 35 to 45 mm seed tuber with the haulm pulling at 75 DAP or 82 DAP or 89 DAP or 96 DAP or 103 DAP. The 40 ppm GA_3 was used to treat the mother seed tuber. The maximum

infected plants ((PMV 3.70%, PVY 2.78 % and PRLV 4.32 %,) were recorded from late haulm pulling (103 DAP) and the minimum infected plants (PMV 0.62 %, PVY 0.31 % and PRLV 0.95 %) were recorded from haulm pulling (75 DAP). The highest (1.85 %) black scarf infected plant was found from the haulm pulling time at 103 DAP. The maximum number (9.93) of seed tubers per plant was recorded from the haulm pulling time of 96 DAP, which was similar with the haulm pulling time of 103 DAP. The lowest number of seed tubers per plant (5.53) was collected from HP at 75 DAP. The maximum seed potato yield (29.28 ton/ha) was recorded from 96 DAP haulm killing which was similar with 89 and 103 DAP haulm killing. The lowest yield (15.58 ton /ha) was recorded from 75 DAP haulm pulling. The highest benefit-cost ratio was observed in of 35-45 mm mother seed tuber with haulm pulling at 96 DAP (2.83). So, 40 ppm GA₃ treated 35-45 mm mother seed potato with haulm pulling at 96 DAP was profitable to seed potato production.

CONCLUSION

From the aforementioned results and discussions, it can be concluded that

- The seed potatoes of positive selection and seed plot technique are the best alternate to supplement the certified seed. Potato farmers can now choose to either buy commercial seed potatoes or practice positive selection or Seed Plot Technique (SPT). Although the positive selection technique does not require any cash investments, it does require an extra labor. Whereas, SPT needs some extra effort and maintenance of isolated field.
- In conventional seed potato production in Dinajpur, Bangladesh, the 4th November is the best planting time with the haulm pulling time at 75 DAP. But for cultivation of table potato the planting time will be the best in the November with haulm pulling time at 82 to 89 DAP.
- For the production of seed potato, before sprouting 40 ppm GA₃ is most suitable to treat 35 to 45 mm size mother seed tuber.
- The use of 20 to 40 ppm GA₃ on below 25 mm mother seed tubers (diameter), can increase the sprouting and germination percentage and yield very effective.
- The 15 to 25 mm seed tubers are comparatively more vulnerable to PLRV infestation.
- The percentage of healthy tuber are decreased, with increasing generation of seed potato. The certified seed or foundation seed reduced yield 4.58 % and 5.64 % at next cropping season, respectively.
- To get better seed potato yield, breeder seed tuber or minitubers are multiplied in field more than 2 consequent year.
- In normal cultivation farmer can multiply the certified seed upto 2 subsequent cropping season. The three times multiplication of minituber and breeder seed for seed production increase wilt infestation near about 1.0 %.
- The 3 times field multiplication of minituber, breeder seed and foundation seed increased PVY infestation upto 1.85%.The minituber and breeder seed multiplication for 3 times increased PLRV infestation upto 2.31%.
- The best size of GA₃ treated mother seed tuber is 35 -45 mm diameter with haulm pulling time at 96 or 89 days after planting (DAP).
- Application of GA₃ at mother seed tuber have positive impact to decrease the common scab of potato.

RECOMMENDATION

The subsequent recommendations are suggested for further research-

- The findings of the study principally focused on suitable planting and haulm pulling time for seed potato treatment on potato production under Dinajpur region of Bangladesh. Thus, it is recommended that further investigation should be undertaken in others location of Bangladesh under such treatments.
- The results of the study also concentrated on appropriate GA₃ dose for seed tuber and suitable seed potato size for using GA₃ for maximizing seed potato yield of Bangladesh. So, further investigation should be undertaken for different application time of GA₃ in potato field.
- This decision was drowning only one potato cultivar namely cardinal. Thus, further research is needed by increasing the number of cultivar that may found better results.
- Molecular study is needed to identify the consequence of GA₃ application on disease susceptibility or tolerance.
- Study is needed for disease development mechanism through PGR application.
- Future research is also needed for determined optimum fertilizer dozes for GA₃ treated potato cultivation.

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APPENDICES

Appendix I. Production cost of potato per hectare

A. Non Material

Sl No	Activities	Labour (Man-day/ha)	Rate (Tk Man/day)	Total (Tk/ha)
1	Land preparation			
	i. Ploughing 4	Power tiller	10 TK/decimel	2470
	ii. Laderring 2	Power tiller	10 TK/decimel	741
2	Fertilizer application	8	200	1600
3	Seed preparation & planting	40	200	8000
4	Insecticide application	12	200	2400
5	Earthing up	40	200	8000
6	Irrigation	6	200	1200
7	Roguing	4	200	800
8	Haulm Pulling	6	200	1200
9	Harvesting	40	200	8000
10	Grading	10	200	2000
11	Packing, weighting, transporting	12	200	2400
12	Land Lease			16000
Total				54811

2. Material input cost

Sl No	Materials	Quantity	Unit Price (Tk)	Total (Tk)
1	Fertilizer			
2	Urea	320 Kg	16/-	5120
3	TSP	150 Kg	22/-	3300
4	MP	209 Kg	15/-	3135
5	Gypsum	120 Kg	25/-	3000
6	Zinc sulphate	85 Kg	150/-	12750
7	Boric acid	10 Kg	200/-	2000
8	Cowdung	15 ton	700/-ton	10500
9	Pesticides			6000
Total				45805

Sub-total cost: Material + Non material Cost = 54811 + 45805 =100616 Tk

Treatments	Seed. Kg	Price (Tk)	Additional Cost (Tk)	Sub Total Cost (Tk)	Production Cost (Tk)
35-45mm+75 DAP	3704	129640	1000	100616	234960
35-45mm+82 DAP	3704	129640	2000	100616	235960
35-45mm+89 DAP	3704	129640	3000	100616	236960
35-45mm+96 DAP	3704	129640	4000	100616	237960
35-45mm+103 DAP	3704	129640	5000	100616	238960
45-55mm+75 DAP	6061	200013	1000	100616	307690
45-55mm+82 DAP	6061	200013	2000	100616	308690
45-55mm+89 DAP	6061	200013	3000	100616	309690
45-55mm+96 DAP	6061	200013	4000	100616	310690
45-55mm+103DAP	6061	200013	5000	100616	311690

[Cell price seed tuber 20Tk/kg and ware potato 7Tk/kg. Seed cost 35 – 45 mm potato 35 Tk/kg and 45-55 mm potato 33 Tk/kg.]

Appendix 2

Weather Data

Parameter	October 2014			November 2014			December 2014		
Humidity (%)	-	-		79.8	80.2	82.9	85.9	85.1	85.5
Minimum (0°C)	23.79	21.48	19.5	18.28	16.15	13.36	13.74	12.16	10.0
Maximum (0°C)	33.98	31.16	30.5	31.64	29.3	26.7	25.5	23.56	23.0
Rainfall (mm)	0	0	0	0	0	0	0	0	0

Parameter	January 2015			February 2015			March 2015		
Humidity (%)	86.3	85.9	85.2	79.3	78.1	82.8	75.1	69.6	78.1
Minimum (0°C)	11.9	9.6	9.9	10.7	13.1	16.8	15.9	15.9	18.7
Maximum (0°C)	21.9	21.3	22.6	25.4	26.3	29.2	29.0	30.9	32.1
Rainfall (mm)	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3

Parameter	October 2015			November 2015			December 2015		
Humidity (%)	84.0	81.8	83.6	83.1	83.0	79.5	86.2	87.6	75.7
Minimum (0°C)	23.6	21.6	20.3	15.4	16.5	14.5	14.5	9.8	7.9
Maximum (0°C)	34.7	32.6	31.6	30.4	29.7	29.7	26.3	22.6	24.8
Rainfall (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Parameter	January 2016			February 2016			March 2016			April 2016		
Humidity (%)	81.8	83.4	85.9	81.2	78.5	76.3	76.1	71.7	74.5	78.9	76.5	76.4
Minimum (0°C)	9.9	8.7	8.6	11.0	13.2	14.6	17.6	16.9	17.9	20.5	21.7	22.6
Maximum (0°C)	25.4	23.8	20.6	25.7	28.7	29.9	32.1	32.1	31.8	32.8	33.8	36.2
Rainfall (mm)	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.4	0.0	0.4

Weather Data

Parameter	October 2016			November 2016			December 2016		
Humidity (%)	89.1	86.8	83.5	81.7	79.6	80.9	84.3	85.7	84.9
Minimum (0°C)	24.2	21.7	20.2	18.5	15.4	14.4	13.4	11.0	11.9
Maximum (0°C)	33.1	31.4	32.4	31.6	30.7	29.5	28.1	24.7	26.2
Rainfall (mm)	5.2	13.4	0.0	-	-	-	0.0	0.0	0.6

Parameter	January 2017			February 2017			March 2017		
Humidity (%)	83.5	78.4	80.8	80.4	76.2	72.7	73.1	75.2	85.2
Minimum (0°C)	11.4	6.9	10.6	11.3	13.0	13.5	13.2	13.6	18.2
Maximum (0°C)	24.6	24.2	26.1	26.5	28.8	29.2	29.8	27.8	28.4
Rainfall (mm)	0.0	0.0	0.4	0.0	0.0	0.0	0.0	3.8	5.4

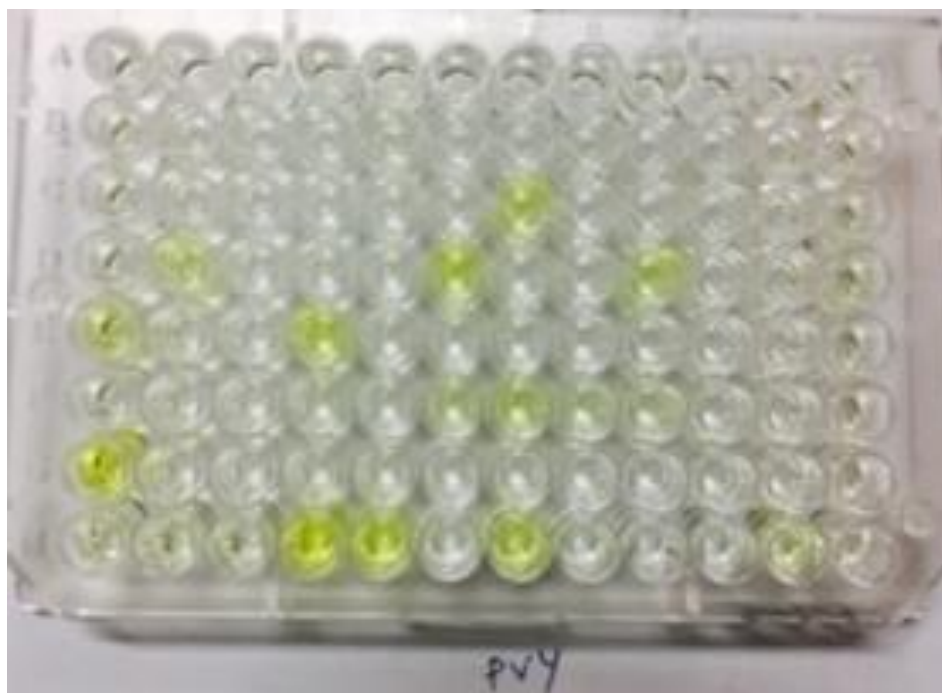
Parameter	October 2017			November 2017			December 2017		
Humidity (%)	-	-	-	-	-	-	82.3	86.9	85.8
Minimum (0°C)	26.8	24.9	20.8	16.5	16.4	13.0	13.8	13.6	12.5
Maximum (0°C)	31.4	31.5	28.6	31.1	30.5	28.1	28.8	26.3	28.1
Rainfall (mm)	44.9	14.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0

Parameter	January 2018			February 2018			March 2018		
Humidity (%)	88.9	93.5	84.2	80.7	76.1	77.8	74.8	71.8	62.3
Minimum (0°C)	8.1	9.1	9.7	11.6	13.1	14.9	16.5	16.4	18.9
Maximum (0°C)	20.2	19.2	23.0	26.0	28.9	30.9	33.4	34.0	34.8
Rainfall (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7

Source: Bangladesh Wheat and Maize research Station, Dinajpur

APPENDIX 3: ELISA TEST

Yellow color indicates positive reaction to PLV



Yellow color indicates positive reaction to PLRV

