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PRODUCTION OF DISEASE FREE SEED POTATO TUBER THROUGH OPTIMIZATION OF PLANTING AND HAULM PULLING TIME

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Abstract

The time for planting and haulm pulling is very crucial for production of quality of seed potato tuber. Thus, the different planting times i.e., 15th October, 4th November, 24th November, and 14th December, and haulm pulling (HP) at 68, 75, 82, and 89 days after planting (DAP) were evaluated to find out the suitable planting time and haulm pulling time for disease-free potato seed production. This study was conducted in the research field of the Plant Pathology Department, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during 2016-2017. The maximum seed potato tuber yield (23.9 ton/ha) was recorded from 4th November planting time with haulm pulling at 82 days after planting. The findings also exhibited that the minimum disease infestation was observed in the same treatment combinations which enhanced the maximum photosynthesis and growth for the plants resulting in higher seed potato yield. Farmers of subtropical regions would be benefitted if they practice these methods.

Keywords: Canker, Diseases incidence, Heat injury, Leaf blight, Tuber yield

Introduction

Potato (*Solanum tuberosum*) is one of the most important food crops grown in more than 100 countries in the world. It is the second most important food crop in Bangladesh next to rice; and is mainly used as vegetables that cover 468626 ha of land where total potato production was 9887 million tons (BBS, 2021). It is also a world-leading crop that furnishes an appreciable amount of Vitamin-B and Vitamin-C as well as some minerals. The average yield of potatoes is 20.8 metric tons per hectare which is very low compared to the potato growing countries. Several factors are responsible for such low yield of potatoes in Bangladesh, where quality potato seed tuber is a crucial one and that is dependable on the optimum planting and haulm pulling time. However, the different planting time in various parts of Bangladesh are practiced, consequently showed

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variable yield potentiality of seed potato. Thus, it should be needed to fix the optimum planting time for higher seed potato yield. The planting time affected tuber quality (Haile *et al*., 2015; Alam *et al.*, 2017), and influenced the emergence percentage, vegetative growth, tuber number, and also the yield of potato (Thongam *et al.*, 2017). Likewise, farmers of Bangladesh harvested seed potato at different times which also influence the quality of seed potato. In addition, the key hinders to potato production have been identified as the unavailability of quality and healthy seed potatoes, complexities of disease-free seeds production and distribution, a wide range of pests and diseases, insufficient cold storage facilities for large-scale seeds, resulting in rotting and sprouting and violent price fluctuation (Hoque and Sultana, 2012). So, it is essential to ensure quality seed potato within the farmer's ability. The main reason for the low yield of potato is the use of poor-quality seeds. Only 10% quality seed potato of the total requirement is being supplied by different governments and other private organizations, and the remaining 90% seed requirement is being mitigated by the farmers' retained seed which is usually of poor quality (Siddique *et al.*, 2015). On the contrary, the quality of seed potato is considered to improve farmers' potato yields and income (Eshetu *et al*., 2005; Hirpa *et al.*, 2005). The haulm pulling time regulates tuber size and quality of seed potato/disease pressure (Virtanen and Seppanen, 2014). Early harvesting can be done by haulm pulling which ensures expected tuber size and tuber skins strengthened as to avoids plant pathogens to spread the vegetative and reproductive organs.The haulm pulling is practiced for seed potato production to protect the seed-borne or soil-borne pathogens, such as; viruses, bacteria, and fungi black scurf (*Rhizoctonia solani*), late blight (*Phytophthora infestans)*, gangrene (*Phoma foveata)*, Verticillium wilt (*Verticillium dahliae)* (Kempenaar and Struik, 2008). Moreover, haulm pulling increases the quality of tubers as after haulm pulling, the skin of the tubers becomes hardened (Hoque *et al.,* 2010).

In addition, various diseases are strongly correlated with planting time and haulm pulling time which is responsible for the quality of seed production in Bangladesh with existing climatic factors (Lutfunnahar *et al*., 2020). But the time of planting and haulm pulling can interact with the plant development and tuber size, quality, and yield of potato (Alam *et al.*, 2017). Hence, the most important factors affecting of growth, yield, and quality of tubers are the planting and harvesting time (Nedunchezhihan and Byju, 2005). As such, the management practice like proper planting time and haulm pulling time of potato can ensure good quality seed by escaping different diseases.The planting and haulm pulling time influence the different soil or seed-borne viral, fungal as well as bacterial diseases. Thus, the study was undertaken to determine the optimum planting time and haulm pilling time for quality seed potato production.

Materials and Methods

Experimental site

The experiment was conducted in the research field of the Plant Pathology Department, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur during 2016-2017. The experimental site was under AEZ-1 (Old Himalayan

Piedmont plain) under the latitude of 25.7^{0}N and longitude 88.65^0 E with an altitude of 37 m from the sea level. The chemical properties of the initial soil of the study field along with metrological data during the crop growing period have been presented in Table 1 and Fig. 1.

Table 1. Chemical properties of the experimental soil (initial) at the experimental field, HSTU, Dinajpur

	P^H	OM (%)	N (%)	P (µg g^{-1})	K (meq100^{-1} g soil)	S (µg g^{-1})	Zn (µg g^{-1})	B (µg g^{-1})
Field Status	5.19	0.65	0.04	13.69	0.21	13.75	1.12	0.17
Critical level			0.12	10.0	0.12	10.0	0.60	0.20

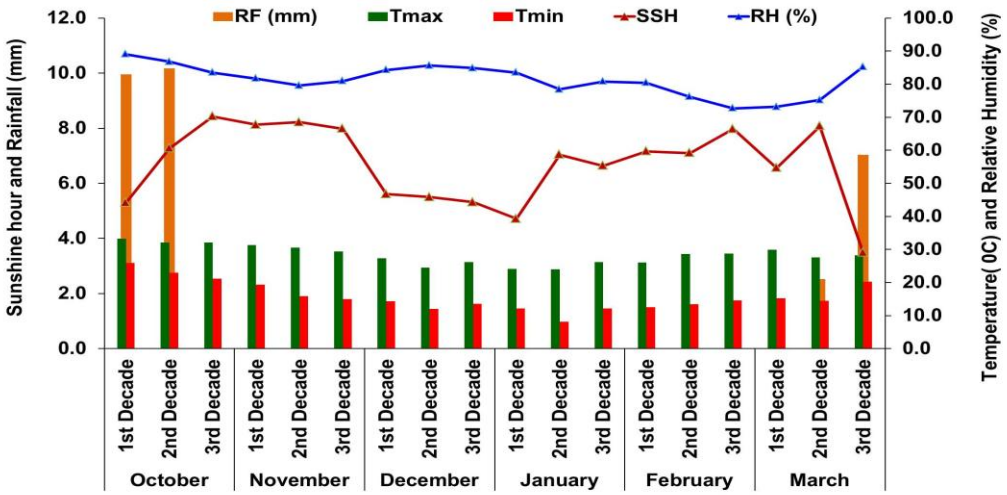

Fig. 1. Decade-wise average maximum temperature, minimum temperature, sunshine hour and rainfall during the cropping period from 2016-2017 at HSTU, Dinajpur

Treatment and design

The experimental design was RCB with two factors (factorial) where the first factor consists of different planting times i.e., i). 15th October, ii). 4th November, iii) 24th November, and iv) 14th December, and the second factor consists of different haulm pulling time i.e., at 68, 75, 82 and 89 DAP. The plant spacing was maintained at 60 cm× 25 cm. The unit plot size was 2.4 m × 3.5 m.

Planting material

The most popular potato variety "Cardinal" was used as a test crop. The saline feature of the test crop are given in below

Developed by	:	Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh
Origin	:	The Netherlands
Year of release	:	1993
Main characteristics	:	Tuber: red, oval, medium size, skin smooth, flesh yellow and shallow eye, stem color reddish violet, plant hard and rapidly growing, number of stem lower but wave-like, seed dormancy 50-60 days in general temperature, crop duration 90-95 days, at first sprout initiation round shape, later it will taller, color bright reddish violet and slightly hairy. This variety is cultivated throughout Bangladesh. Farmers themselves can grow seeds.
Planting season	:	Rabi (November).
Yield potentiality	:	25-30 t/ha

Crop management

Fertilizers were applied @ N-P-K-S-Mg-Zn-B as of 90-20-90-10-5-2-0.5 kg ha^{-1} and cowdung @ 5 t ha^{-1}. Half of N and the full dose of other fertilizers were applied as basal doses before final land preparation (BARC, 2012). The rest half of N was side-dressed at 35 DAP. The seed tubers were taken out from the cold storage 10 days before planting and were spread over the floor under diffused light for sprouting. The good-looking, healthy, and well-sprouted whole tubers were used for planting. Planting was done at the depth of 5-7 cm apart with time. Earthing up was done two times, the first was just after planting and the second was at 35 DAP. One weeding was done at 35 DAP. Irrigation was provided thrice times at 10, 35, and 50 DAP. For controlling insect pest (cutworm and aphid), Dursban @ 5 ml per liter of water and Metasystox @ 1 ml per liter of water was applied respectively. The fungicide Mencozeb @ 2.0 mg per liter was sprayed at every 10 days interval from 20 DAP as a routine spray to keep the potato plants free from late blight infection. After taking the aforementioned protection, if the symptoms of late blight diseases were observed, Acrobate HZ 72 @ 2.0 mg per liter and Melody due @ 2.0 mg per liter were used two times at 3 days intervals to control the late blight. The planting and haulm pulling times of the crop were maintained according to the treatments. Ten plants were harvested for the first time from each plot for data collection. The yield was measured on a whole plot basis. The emergence of potato per plot was recorded by eye observation at 20 DAP and 30 DAP. Yield-contributing traits were recorded from five representative plants in each plot. Data were recorded as follows-

i. The leaf area coverage was estimated using the method outlined by Burstall and Harris (1983).

ii. The percent disease incidence of different diseases was recorded by the following formula-

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

iii. Foliage infection by the late blight (LB) disease was measured according to disease severity 1-9 scale (Rahman *et al.*, 2008) as follows:

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 a 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: up to 1 in 10 leaflets 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 a 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 is destroyed.

iv. Present disease index (PDI) was estimated from 16 randomly selected plants from each plot (Rahman *et al.*, 2008):

$$PDI = \frac{Class\ frequency}{No.plants\ assessed \times Highest\ score\ of\ scale} \times 100$$

v. ELISA test

Seed collected from the virus-infected plants were kept separately for ELISA test. DAS-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. Tubers were graded into four categories

namely oversize (> 55 mm), "B" grade (40-55 mm), "A" grade (28-40 mm), and small size (10-28 mm). The number of infected tubers by Common scab, *Rhizoctonia* canker, or deformed tuber was counted by eye inspection of the tubers at room storage condition.

Disease index and incidence of common scab

The treatments were categorized into different disease reactions according to the disease scale described earlier (Patel, 1991) as given below. The disease rating scale for the common scab of potato was done according to 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 (%) were calculated according to the equations given below

$$\textit{Disease index} = \frac{\textit{Total number of infected tubers} \times \times \textit{Disease rating}}{\textit{Total number of tubers}} \times 100$$

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

Disease index and incidence of *Rhizoctonia* canker of potato

The treatments were categorized into different disease reactions according to the disease scale described earlier (Kulkarni and Chavhan, 2017) as given below.

Disease Rating Scale (*Rhizoctonia* canker): Observations were done by using a 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

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

$$\textit{Disease index of Rhizoctonia canker} = \frac{\textit{Total number of infected tubers} \times \textit{Disease rating}}{\textit{Total number of tubers}}$$

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

Estimation of deformed tuber

The percentage of deformed tuber was calculated using the following formula: Deformed tuber (%) = (Number of deformed tubers/Total tuber) x 100.

Statistical analysis

Data were analyzed by using the statistical computer package program, MSTAT-C (Russell, 1986) to find out the levels of significance of the experimental results. Duncan's Multiple Range Test (DMRT) at a 5% level of probability was used for the mean comparison.

Results and Discussion

Effects of planting time on the emergence of potato

Percent seed potato emergence at different dates of data collection differed significantly (Table 2). At 20 DAP, the maximum 88.02% emergence was recorded when the seed potato was planted on 14th December, which was similar to 4th November. The seed potato emergence percentage was increased at 30 DAP. The maximum 100% emergence was recorded at potato planting time of 4th November, 24 November and 14 December, and the minimum 74.48% seed emergence was observed when the potato was planted on 15 October. This happened due to high temperatures along with high soil moisture because of rainfall, which enhanced the rot of seed tubers. These results indicate that the emergence of seed potato had no effect at the planting time of early November to mid-December. Similar results were also reported by Afsana (2018) who recorded a maximum of 99.7% seed emergence at the planting time of 1st November and a minimum of 88.5% at the planting time of 2nd October. Comparatively soil moisture and temperature in November are congenial to potato cultivation in Bangladesh which enhances the emergence and better plant growth. Jamro *et al.,* (2015) establish the maximum of 84.95% emergence of potato at the planting time of 30th October. The earliest planting date of 30th September in Maharastra, India recorded the maximum emergence of potato at 15 and 30 DAP reported by Thongam *et al.,* (2017). Alternatively, the early planting of potato on October 20 delayed emergences was reported by Bewuketun *et al.,* (2015). Alam *et al.,* (2017) stated that from 31 October to 30 November, planting time is suitable for the emergence of seed potato in Bangladesh due to favorable agro-climatic conditions.

Influence of planting time on plant height and stem number per hill

The plant height varied significantly at haulm pulling time (Table 2). The maximum plant height (56.9 cm) was recorded at the planting time of 15th October which was statistically similar to 4th November (52.3 cm) and 24th November (53.5 cm). On the other hand, the minimum plant height (47.3 cm) was observed when data was recorded on 14th December. These differences in plant height might be due to attribute different prevailing weather conditions at various planting times. The most favorable environment remained on 15th October, a long period of high temperature for plant growth during the cropping season. But, the planting time of 14th December gave the lowest plant height (47.2 cm) due to faced lower temperature along with a short growth period which reduced the allocation of assimilates for growth, practiced compared to

other planting dates by the plants after emergence than three planting dates. After mid-February or 50-55 DAP the plants experienced higher temperatures than on other planting dates due to climatic conditions. The results are in line with the findings of Sandhu *et al.*, (2012), Ezekiel and Bhargava (1992), Alam *et al.*, (2017), Afsana (2018), and Monsor (2014).

Table 2. Effect of planting time on vegetative growth of seed potato

Planting time	Emergence at 20 DAP (%)	Emergence at 30 DAP (%)	Plant height (cm) at HP time	Stem per hill (No.) at 30 DAP	Leaf Area Coverage (%) at 60 DAP	Canopy wt/pl (g) at HP
15th October	61.5 (4.33)	74.5 (4.77)	56.9	2.77	61.1 (49.84)	103.7
04th November	79.7 (4.94)	100.0 (5.54)	52.3	5.40	89.5 (69.19)	209.7
24th November	65.1 (4.40)	100.0 (5.54)	53.45	4.67	88.7 (68.22)	164.4
14th December	88.02 (5.19)	100.00 (5.54)	47.25	5.47	83.67 (64.18)	68.9
$LSD_{0.5}$	0.41	0.12	4.9	0.72	5.8	31.2
CV%	10.4	2.82	11.16	18.93	11.08	27.4
LS	**	**	**	**	**	**

LS= Level of significance; *=significant at p=0.05; **significant at p=0.01; Parenthesis indicate the transformed value (1st and 5th column Arcsine, 2nd column Square root).

Effects of planting time on stem number per hill

The results showed that the stem number per hill was influenced by different planting times (Table 2). At 30 DAP the maximum number (5.47) of stem per hill was observed when the seed was sown on 14th December which was similar to seed planting on 4th November. The minimum number (2.77) of stems per hill was counted when the seed was sown on 15th October. The cumulative age of seed tubers was higher at late planting and more desprouting was needed before planting which was responsible for more sprouting and more stem per plant. As per the results of Alam *et al.*, (2017), there was no significant influence on stem per hill by the early to late November dates of planting of potato. The stem number per plant differed based on very early planting time (Mid-October) with other planting times (November to Mid. December), according to Afsana (2018) and Bewuketun *et al.*, (2015).

Effects of planting time on leaf area coverage and canopy weight

Percent leaf area coverage (LAC) varied significantly with different planting times of potato. Regarding 60 DAP, the highest LAC (89.5 %) was found at the planting time of 04th November which was similar to 24th November (88.7%) and 14th December (83.7%). But, the lowest LAC (61.1 %) was found at the planting time of 15th October (Table 2). Comparatively highest plant height with maximum stems per plant is responsible for higher canopy coverage. The different planting times on canopy weight per plant also varied significantly (Table 3). The highest canopy weight (209.7 g) per

plant was recorded from the planting time of 4th November. The lowest canopy weight (68.9 g) per plant was recorded at the planting time of 14th December. The winter season in Bangladesh, mainly from November to early February, was the best environmental condition for proper growth and development of potato, so early November planting time performed better in canopy weight per plant due to finding a longer winter life cycle and can synthesize and accumulate more carbohydrates in the canopy. The result is supported by the finding of Alam *et al*., (2017) and Bahram *et al.*, (2012), who stated that early planting is most suitable for vegetative development and yield of potato.

Effects of different haulm pulling time on leaf area coverage and canopy weight

The different haulm pulling (HP) time on the leaf area coverage (LAC) was significant (Fig. 2). The highest LAC (79.7%) was found in the haulm pulling of 68 DAP which was similar to the haulm pulling of 75 DAP and followed the haulm pulling of 82 DAP. The lowest LAC (40.8 %) was found in the haulm pulling of 89 DAP. Delaying haulm pulling time decreases the LAC of potato after the vegetative stage or from the maturity stage the plants are dried and weathered day by day. Moreover, the effect of haulm pulling times on the canopy weight per plant also varied significantly (Fig. 2). The highest weight (181.8 g) of canopy per plant was counted from the haulm pulling time of 75 DAP which was similar to 68 DAP and followed 82 DAP. The lowest weight (60.3 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 reduces the water content, defoliates the leaves and stems, and may transfer 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), who stated that ground coverage is related to the plant height and leaves number per plant.

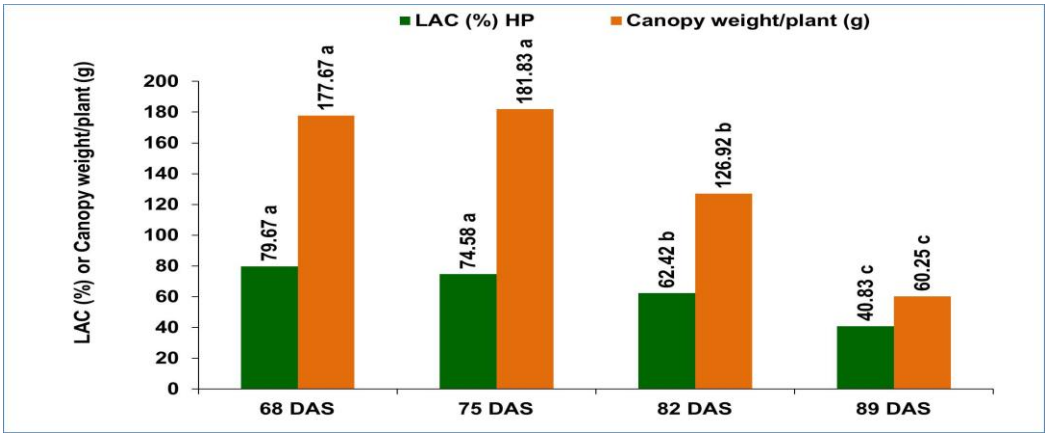

Fig. 2. Effects of different haulm pulling (HP) time on LAC and canopy weight of the potato

Effects of planting time on late blight of potato

Late blight (LB) of potatoes was observed in 1st week of January 2017 due to the presence of low temperatures and foggy weather (Table 3). The data revealed that different planting times on natural LB development on 05 January 2017 varied significantly among the observations. Maximum late blight infestation (2.90%) and LB severity i.e. PDI (21.81) was recorded in the 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 on 24th November. On 5th January, plants were at the growth stage of 82, 62, 42, and 22 days in respect of chronological different planting times. The highest infection percent and PDI of late blight were found at the planting time of 24th November which was followed by 4th November and 14th December. The lowest infection percent and PDI of late blight were recorded at the planting time of 15th October. On 18th January 2017, the highest LB infestation and PDI were also recorded at planting time of 24th November. On the other hand, the lowest LB infestation and PDI were also recorded at the planting time of 15th October (Table 3). The late planting showed the first appearance of late blight and rapid progress of late blight. The results conform to the findings of Afsana (2018) and Singh and Pundhir (2012) who stated that different planting times influence the late blight development of potato.

Effects of planting time on disease and heat injury

The effect of different planting times on the naturally occurring potato leaf roll virus (PRLV) was significant at only haulm pulling time. The maximum percentage (4.17%) of PLRV was identified at the 4th of November planting time which was similar to the 15th of October. The minimum percentage (0.52 %) of PLRV was identified on 14th December. In the case of potato mosaic virus (PMV) at 45 DAP, there were significant variations. The maximum percentage (2.60%) of PMV was identified on the 24th of November planting time which was followed by the 4th of November. At haulm pulling time, the highest percentage (9.38%) of PMV-affected plants was counted from 24th November which was followed by 14th December. In the case of potato virus Y (PVY), at 60 DAP, the 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 (Fig. 3). Delaying the planting time of potato in Bangladesh, ensure climate warmth in the vegetative stage of potato and increase the potato virus disease due to vector (aphid) spread in the field. These results are in agreement with the finding of Monsor (2014), Rahman and Akanda (2010), Halim (1999), and Afsana (2018).

Table 3. Effect of different planting times on late blight (LB) development

Planting time	05 January 2017		11 January 2017		18 January 2017	
	% LB	PDI	% LB	PDI	% Disease	PDI
15th October	0.46 (1.07)	13.74	0.42 (1.04)	13.41	0.00 (0.84)	12.50
04th November	1.29 (1.40)	17.25	1.74 (1.52)	17.97	1.54(1.39)	17.58
24th November	2.90 (1.88)	21.81	3.08 (1.94)	25.13	6.25 (2.63)	30.47
14th December	0.29 (0.99)	13.09	1.68 (1.53)	16.60	1.87(1.58)	17.64
$LSD_{0.5}$	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
LS	***	***	***	***	***	***

LS= Level of significance; ***significant at p=0.001; parenthesis indicate transformed value

The incidence of bacterial wilt of potato plants varied significantly in different planting times observed (Fig. 3). The 14th December planting time performed the 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 on 15th October. The effect of different planting times on the Heat injury varied significantly. Only at the planting time of 14th December showed heat injury (Fig. 3). Daley planting time, mid-December, increase the wilt and heat injury due to warmed weather from the 2nd week of February when the plants were at the vegetative stage (55 DAP). Struik (2007) stated that temperatures higher than 25°C can enhance stem growth and branching, and increase the leaf number, but cause a reduction in leaf size and total leaf area. These results are also supported by the findings of Wahid *et al.,* (2007) and Rykaczewska, (2013).

Effects of haulm pulling time on disease and heat injury

The effect of different haulm pulling times on the naturally occurring PRLV, PMV, and PVY was significant (Fig. 4). 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, the vectors ensure more time for spreading which increases the viral diseases. These results are in agreement with the finding of Monsor (2014).

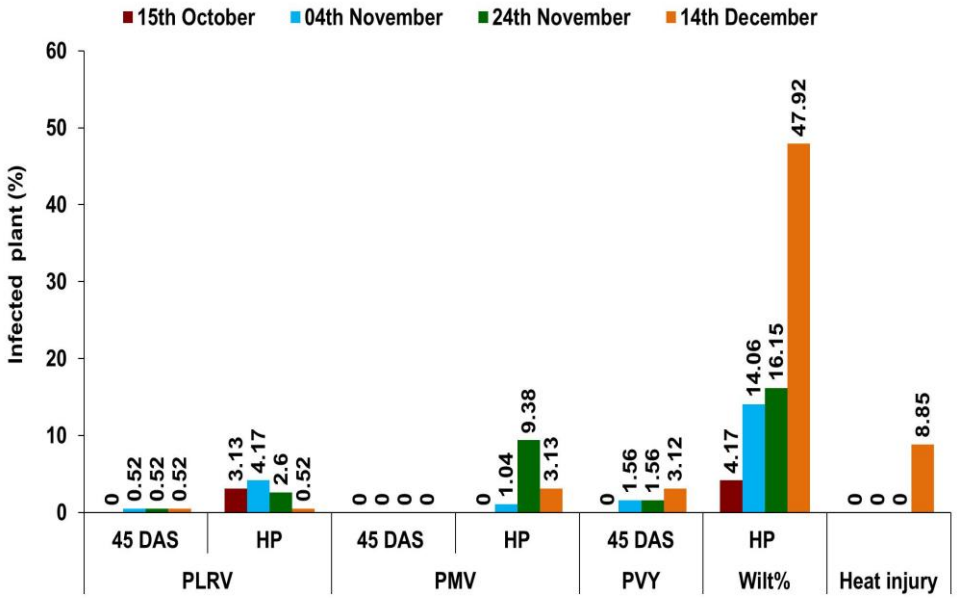

Fig. 3. Effects of different planting times on PLRV, PMV, PVY, wilt and Heat Injury

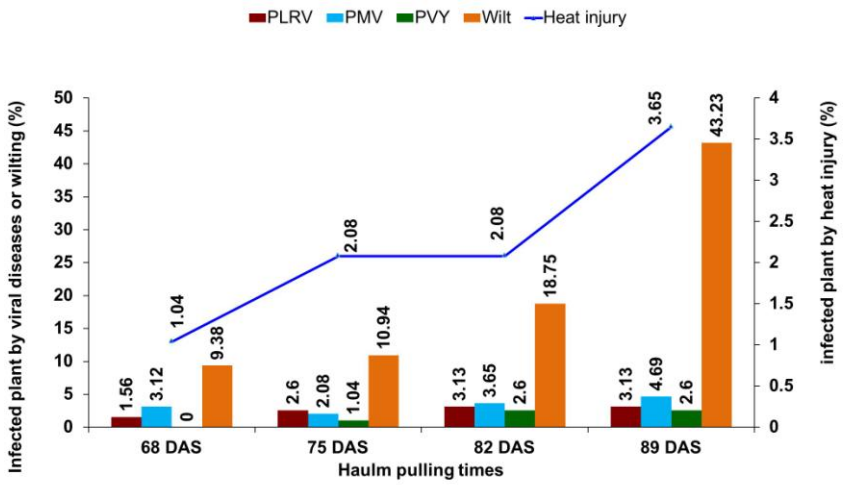

Fig. 4. Effects of haulm pulling time on PLRV, PMV, PVY, wilt, and heat injury of potato

The incidence of bacterial wilt of potato plants varied significantly in different Haulm pulling times (Fig.4). The highest (43.23 %) bacterial wilt infected plant was found in late Haulm pulling at 89 DAP, which is similar to at haulm pulling time 82 DAP. Minimum (9.38%) plants were wilted when haulm pulling early (68 DAP or 75 DAP). If haulm pulling is delayed, the temperature is increased which enhances microbial activities. So the incidence of wilting is enhanced. The result is supported by the finding

of Karan YB (2021) and Anonymous (2017) where it was stated that moist and warm environments are encouraging the development of bacterial wilt disease, which depends on species, age, and resistance of the host and environmental conditions. According to Anonymous (2017), Bacterial wilt disease development is favored by warm temperatures (25°C-30°C) and low temperatures (10°C), and the bacterium cannot survive in dry soil conditions.

Different haulm pulling times significantly varied the heat injury of potato specially planted on 14th December. The maximum (3.65%) plants were injured by heat at the time of haulm pulling 89 DAP which was similar to 82, 75 DAP. The minimum (1.04%) plants were injured by heat at the time of haulm pulling 68 DAP (Fig. 4). From the last week of January, the temperature increased rapidly which directly affect the development of crops of mid-December planting time. These results are corroborated by the finding of Wahid *et al.,* (2007) and Rykaczewska, (2013). According to Wahid *et al.,* (2007), an array of morpho-anatomical, physiological, and biochemical changes in plants are caused by transitory or constant a high temperatures, which affects the plant growth and development reducing the economic yield. According to Rykaczewska (2013), the response of potato plants to high temperatures during the growing season is related to the growth stage. For the growth and yield of potato, the impact of high temperatures of 32˚C/25˚C on potato plants was more negative.

Effects of planting times on yield and yield component of potato

The different planting times significantly affected the total tuber number and weight per plant, seed-tuber number and weight per plant, potato yield, and seed-potato yield (Table 4). The maximum tuber number (11.07) was counted from the late planting time i.e. 14th December which was followed by 4th November and the minimum number (7.33) of tuber was found on 24th November. The highest number of seed tubers per plant (7.65) was recorded from the planting time of 14th December which was similar to 4th November (6.92) and followed by 24th November (5.93). The lowest number of seed tubers per plant (4.63) was collected on the 15th of October. In the case of the planting on 14th December, the seed tubers were collected 20 days before planting time. So the collected seeds were de-sprouted one time before final sprouting. For this reason, the stem number per plant and the tuber number per hill were increased. The maximum weights (400.23 g) of total tuber per plant were recorded from the planting time of 4th November which was similar to the planting time of 24th November. The minimum weight (332.07 g) of the tuber was observed during the planting time of 15th October which was similar to the planting time of 14th December. A 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 to 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 was also found in different planting times. The highest weight (342.77 g) per plant was recorded from 4th November which was similar to 24th November. The minimum weight (217.77 g) was counted from 15th October (Table 4). These results are consistence with many workers (Thongam *et al.,* (2017),

Alam *et al.,* (2017), Monsor (2014), 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.

Effects of haulm pulling times on yield and yield component of potato

In the case of the total number of tuber per plant, the highest number (9.78) was found in 82 DAP which was similar to 75 and 89 DAP. The minimum number (8.15) of total seed tuber was recorded from the haulm pulling time of 68 DAP due to less formation of tubers (Table 4). The results are corroborated by Alam *et al.,* (2017), Monsur (2014), and Bahram *et al.,* (2012), who found that harvesting dates influenced tuber number per plant significantly. The maximum weight (385.20 g) of total tuber was recorded from the haulm pulling time at 82 DAP which was statistically similar to 75 and 89 DAP. The minimum weight (285.80 g) of the tuber was observed from the haulm pulling at 68 DAP. The maximum potato yield (22.02 ton ha^{-1}) was recorded from the haulm pulling at 89 DAP which was similar to haulm pulling at 82 and 75 DAP. The lowest yield (17.45 tons/ha) was recorded from haulm pulling at 68 DAP. The maximum seed yield (18.41 ton ha^{-1}) was recorded from haulm pulling at 82 DAP which was similar to haulm pulling at 89 and 75 DAP. The lowest yield (15.94 ton ha^{-1}) was recorded from haulm pulling at 68 DAP (Table 4). The potato plants matured at 75 DAP after that the carbohydrate accumulation rate decreased. The earlier study reported that harvesting dates influenced the yield of potato (Alam *et al.,* 2017; Jamro *et al.,* 2015; Monsor 2014; Sandhu *et al.,* 2012; Bahram *et al.,* 2012; Virtanen and Seppanen 2014 and Hussain 1992.

Effects of different planting times on the grading of potato

The smallest-sized (10 - 28 mm) tuber weight was not varied significantly, but the tuber number was different among the treatments of different planting times (Table 5). The maximum smallest tuber number per plant (3.42) was produced from the planting time of 14th December which was statistically different from the other three dates 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 were counted from 14th 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 were 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 were produced from the planting time of 4th November which was statistically similar to the planting time of 15th October and 24th November. In the case of 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 sized tubers were found in the planting time of 14th December (Table 5). The grades of potato depend on the duration of their life span, which is influenced by different planting times (Monsur, 2014).

Table 4. Effect of planting and haulm pulling times on yield and yield component of potato

Treatment	Tubers /plant	Seeds/ plant	Tuber wt/plant	Seed weight/plant (g)	Yield (ton ha^{-1})	Seed Yield(ton ha^{-1})
Planting time						
15th October	7.33	4.63	332.07	271.77	15.31	12.32
04th November	9.70	6.92	400.23	342.77	24.28	20.85
24th November	8.27	5.93	358.10	315.58	24.28	21.51
14th December	11.07	7.65	332.88	303.23	17.38	15.85
$LSD_{0.5}$	1.15	NS	44.78	39.80	3.92	1.99
CV(%)	15.21	16.9	15.09	15.48	11.56	13.52
LS	***		**	**	***	***
Haulm pulling time						
68 DAP	8.15	4.63	285.80	260.87	17.45	15.94
75 DAP	9.13	6.92	376.27	337.18	20.19	18.11
82 DAP	9.78	5.93	385.20	325.85	21.59	18.41
89 DAP	9.30	7.65	376.02	309.45	22.02	18.07
$LSD_{0.5}$	1.15	0.89	44.78	39.80	3.92	1.99
CV(%)	15.21	16.9	15.09	15.48	11.56	13.52
LS	*		***	**	***	*
Planting times × Haulm pulling Time						
$LSD_{0.05}$	4.21	NS	163.45	NS	7.15	7.25
CV%	15.21	16.9	15.09	15.48	11.56	13.52
LS	-	NS	-	NS	**	-

LS= Level of significance; NS= Non significant; *significant at p=0.05; **significant at p=0.01; ***significant at p=0.001

Effects of different haulm pulling time on the grading of potato

The effect of different haulm pulling times on "B" grade (40 - 55 mm) tuber and oversize (< 55mm) tuber per plant varied significantly (Table 5). 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 were recorded from the haulm pulling time of 68 DAP. Moreover, maximum weight (45.65 g) and number (0.32) of 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 size seed tubers were collected from the haulm pulling time of 68 DAP. The grades of potato are influenced by different haulm pulling time, which affects the tuber formation (Alam *et al.,* 2017 Monsor 2014).

Table 5. Effects of different planting time and haulm pulling time on the grading of potato

Treatments	10-28 mm (below size) tuber plant^{-1}		28-40 mm (A grade) tuber plant^{-1}		40-55 mm (B grade) tuber plant^{-1}		> 55mm (Oversize) tuber plant^{-1}	
	Wt.(g)	Number	Wt.(g)	Number	Wt.(g)	Number	Wt.(g)	Number
Planting times								
15th October	14.6	2.40	73.8	2.25	198.0	2.38	45.7	0.30
04th November	40.2	2.65	124.3	4.10	218.5	2.82	17.2	0.13
24th November	19.1	2.18	107.8	3.37	207.8	2.57	23.5	0.15
14th December	29.7	3.42	201.6	5.95	101.7	1.70	0.0	0.00
$LSD_{0.5}$	37.83	0.88	27.21	0.89	36.31	0.46	23.74	0.14
CV (%)	101.20	39.49	25.72	27.4	24.00	23.19	131.82	112.56
LS	NS	*	**	**	***	***	**	***
Haulm pulling Time								
68 DAP	20.8	2.37	131.3	4.03	129.6	1.72	4.1	0.03
75 DAP	34.3	2.55	131.9	3.90	205.3	2.65	4.8	0.03
82 DAP	27.5	3.17	117.2	3.82	208.6	2.60	31.8	0.20
89 DAP	20.9	2.57	127.2	3.92	182.3	2.50	45.7	0.32
LSD.5	37.83	0.88	NS	NS	36.31	0.46	23.74	0.14
CV(%)	101.20	39.49	25.72	27.4	24.00	23.19	131.82	112.56
LS	NS	NS	NS	NS	***	***	****	***
Planting times × Haulm pulling Time								
$LSD_{0.05}$	43.69	1.75	99.30	3.27	132.533	1.6702	86.64	0.50
CV%	101.20	39.49	25.72	27.4	24.00	23.19	131.82	112.56
LS	NS	NS	NS	NS	NS	NS	NS	NS

LS= Level of significance; NS= Non significant; *significant at p=0.05; **significant at p=0.01; ***significant at p=0.001

Effects of planting times on tuber's common scab and *Rhizoctonia* canker

A significant effect on the common scab of potato was found at different planting times (Table 6). The disease incidence (25.16%) and PDI (Percent Disease Index) (42.55) of common scabs were highest in the field of planting time 15th October and the lowest incidence percentage (10.06) and PDI (13.03) of common scabs was in planting time 14th December (Table 6). From the result, it was revealed that delayed planting time decreases the common scab of potato. Delayed planting time faced comparatively low temperatures from seedling to vegetative stage and got high temperatures from mid-February to onward (tuber development stage) than early planting, which may cause a low infestation of common scab. The results are just altering the results of Waterer (2002), who noticed that the yields and grade-out of potato tuber were influenced by the planting and haulm

pulling times due to tuber damage by common scab (*Streptomyces* spp.). The relatively high temperature (25-30°C) is suitable for the growth of *S. scabies*is, and more severe losses are done by a scab in warm regions or growing seasons (Hooker 1981; Loria *et al.,* 1997). Appropriate planting of potato reduces the crop's exposure to temperatures suited to the growth of the scab lesions and may decrease crop losses, which does not excessively hamper crop productivity.

Table 6. Effect of planting time and haulm pulling time on common scab and *Rhizoctonia* canker of potato

Treatments	Common scab		*Rhizoctonia* canker	
	% Disease incidence	PDI (% Disease Index)	% Disease incidence	PDI (%Disease Index)
Planting time				
15th October	25.16(4.97)	42.55(6.41)	21.11(4.46)	0.49
04th November	19.24(4.22)	32.98(5.24)	9.17(2.95)	0.13
24th November	14.37(3.84)	22.36(4.63)	9.73(3.10)	0.17
14th December	10.06(3.15)	13.03(3.46)	5.21(2.29)	0.06
$LSD_{0.5}$	0.87	1.51	0.7643	0.3139
CV(%)	25.65	36.71	28.66	88.15
LS	**	**	***	***
Haulm pulling time				
68 DAP	14.76	20.82	7.81(2.66)	0.11
75 DAP	15.88	27.88	7.96(2.83)	0.09
82 DAP	20.42	30.35	13.56(3.62)	0.25
89 DAP	17.77	31.86	15.88(3.69)	0.41
LSD.5	0.87	1.51	0.7643	0.3139
CV(%)	25.65	36.71	28.66	88.15
LS	NS	NS	NS	*
Planting time× Haulm pulling time				
$LSD_{0.05}$	3.1574	3.02	2.7898	0.5729
CV%	25.65	36.71	28.66	88.15
LS	NS	NS	NS	***

LS= Level of significance; NS= Non significant; *significant at p=0.05; **significant at p=0.01; ***significant at p=0.00

The statistical difference was found in the effect of different planting times on *Rhizoctonia* canker on tubers. The maximum disease incidence (21.11) percentage and PDI (0.49) of *Rhizoctonia* canker potato was in the planting time 15th of October and the minimum disease incidence (5.21) percentage and PDI (0.06) of *Rhizoctonia* canker of potato was in planting time 14th December (Table 6). Early planting increases the *Rhizoctonia* canker on tubers. The suitable temperature for *Rhizoctonia* canker is below 10˚C and above 24˚C (Mulder and Turkensteen, 2005). Moreover, the Expansion of

these diseases is favored by soil temperatures between 16 to 23°C, while the severity of canker is reduced by soil temperatures above 25°C reported by Anderson (1982).

Effects of different haulm pulling time on common scab and *Rhizoctonia* canker

There was no significant effect among the treatments of different haulm pulling times on the case of common scab, but *Rhizoctonia* canker of potato (Table 6). The maximum % disease incidence (20.42) and PDI (30.35) of common scab on tubers were counted from the seeds of the haulm pulling at 82 DAP. The minimum % disease incidence (7.81) and PDI (0.11) of Rhizoctonia canker on tubers were counted from the seeds of the haulm pulling at 68 DAP. Delay haulm pulling increases the *Rhizoctonia* canker incidence of the tuber. These results are supported by Mulder *et al.,* (1992); Lootsma and Scholte, (1996), and Kumar *et al.*, (2017), who opined that Green-crop-harvesting and immature-crop-harvesting, i.e., early haulm pulling often result in low levels of infection of *Rhizoctonia* canker.

Conclusion

From the above results, it may be concluded that for quality seed potato cultivation, planting and haulm pulling time is very important for seed tuber and tuber production of potato. The 1st week of November is the best planting time and 75 - 82 days after planting is the best haulm pulling time for seed potato production in Bangladesh due to the lowest disease infestation and the maximum yield of potato.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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