EFFECT OF IRRIGATION FREQUENCY AND TIME OF HARVEST ON GROWTH, YIELD AND QUALITY OF POTATO

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CERTIFICATE

*This is to certify that thesis entitled, "**EFFECT OF IRRIGATION FREQUENCY AND TIME OF HARVEST ON GROWTH, YIELD AND QUALITY OF POTATO**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) in AGRONOMY**, embodies the result of a piece of bona-fide research work carried out by **SUBROTO KUMAR ROY**, Registration no. **19-10221** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

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ABSTRACT

The field experiment was conducted at Sher-e-Bangla Agricultural University during the period from October, 2020 to March, 2021 to find out the effect of irrigation frequency and harvesting time on growth, yield and quality of export potato. The experiment had two factors. Factor A: Irrigation frequency: 3 levels; I_1: 3 irrigation at 15, 45 and 60 DAP, I_2: 4 irrigation at 15, 30, 45 and 60 DAP, I_3: 5 irrigation at 15, 30, 45, 60 and 75 DAP and Factor B: harvesting time: 4 times; H_1: harvesting at 85 DAP, H_2: harvesting at 90 DAP, H_3: harvesting at 95 DAP and H_4: harvesting at 100 DAP. The experiment was laid out in a split-plot design with three (3) replications. The variety was BARI Alu-29 (Courage). Data on different growth, yield and quality parameters of potato were recorded and significant variation was recorded for different treatment. In case of irrigation frequency, the maximum number of tubers hill^{-1} (11.65),the maximum tuber weight hill^{-1} (395.40 g), the highest yield of tuber (32.94 t ha^{-1}) was found from I_3treatment.The highest starch content on potato (17.45 mg g^{-1} FW) and the maximum reducing sugar value (0.443 mg g^{-1} FW) was recorded from 3 Irrigation (I_1) treatment. The highest canned potato production was produced in 5 Irrigation (8.24 t ha^{-1}) while the highest flakes potato production (14.83 t ha^{-1}) and the maximum chips potato production (9.88 t ha^{-1}) were obtained from I_3 treatment.In case of harvesting date, the maximum number of tubers hill^{-1} (11.53) at '95 DAP' harvest (H_3) treatment whereas the maximum tuber weight hill^{-1} (390.30 g) and the highest tuber yield (32.59 t ha^{-1}) were recorded from the harvest at 100 DAP (H_4) treatment.The highest specific gravity of tuber (1.058 g cm^{-3}), the maximum dry matter content of tuber (22.17 %) and the highest starch content of tuber (16.27 mg g^{-1} FW) was recorded from potato harvested at 100 DAP.In the case of interaction effects of irrigation frequency and harvesting date, the maximum number of tubers hill^{-1} (12.23), the maximum weight of tubers hill^{-1} (435.38 g) and the highest tuber yield (36.31 t ha^{-1}) were recorded from the combination of I_3H_4 treatment. Among the 12 treatment combinations, '5 Irrigation frequency' exhibited the highest specific gravity (1.070 g cm^{-3}) and the maximum DM content (22.67 %) at 100 DAP. The highest starch content on potato (17.70 mg g^{-1} FW) was attained by I_3H_4 treatment combination. The highest canned potato production (9.08 t ha^{-1}), the highest (16.34 t ha^{-1}) flakes potato production and the maximum (10.89 t ha^{-1}) chips potato production exhibited by I_3H_4 treatment combination. Therefore,application of 5 Irrigation with 100 DAP harvesting date combination seemed to be more suitable for getting higher tuber yield with good quality.

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LIST OF ABBREVIATIONS

ABBREVIATION	ELLABORATION
AEZ	Agro-Ecological Zone
Agric.	Agriculture
Agron.	Agronomy
Annu.	Annual
Appl.	Applied
Vm	Vermicompost
Biol.	Biology
Chem.	Chemistry
cm	Centi-meter
CV	Coefficient of Variance
DAS	Days After Storage
DAP	Days After Planting
Dev.	Development
Ecol.	Ecology
Environ.	Environmental
etc.	and others
Exptl.	Experimental
g	Gram (s)
Hortc.	Horticulture
i.e.	that is
J.	Journal
kg	Kilogram (s)
LSD	Least Significant Difference
M.S.	Master of Science
m^2	Meter squares
mg	Milligram
Nutr.	Nutrition
Physiol.	Physiological
Progress.	Progressive
Res.	Research
SAU	Sher-e-Bangla Agricultural University
Sci.	Science
T	Tuber size
Soc.	Society
SRDI	Soil Resource Development
Institutet ha^{-1}	Ton per hectare
UNDP	United Nations Development Programme
Viz	*videlicet* (L.), Namely
%	Percentage
@	At the rate of
µ Mol	Micromole

LIST OF ABBREVIATIONS

BBS	Bangladesh Bureau of Statistics
cv.	Cultivar (s)
DAS	Days After Sowing
eds.	editors
et al.	et alia (and others)
etc.	et cetera (and other similar things)
FAO	Food and Agriculture Organization
L.	Linnaeus
i.e.	id est (that is)
MoP	Muriate of Potash
TDM	Total Dry Matter
TSP	Triple Super Phosphate
var.	variety

CHAPTER I

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a tuber crop belonging to the family *Solanaceae* is one of the most important vegetable crops of the world. It is originated in the Peru-Bolivian region in the Andes of South America (Grewal *et al.*, 1992). It is the 4th most important food crop in the world after rice, wheat and maize. Bangladesh is the 7th potato producing country in the world. In Bangladesh, it ranks second after rice in production (FAOSTAT, 2018) with a total production of about 8.8 million tons in 2019-2020 (FAOSTAT, 2020). The total area under potato crops, ha^{-1} yield and total production in Bangladesh are 444534.41 hectares, 19.35 t ha^{-1}, and 8603000 metric ton respectively (BBS, 2020). It contributes as much as 55% of the total vegetable demand in Bangladesh (BBS, 2016). The total production is increasing day by day as such consumption also rapidly increasing in Bangladesh (BBS, 2021).

Potato is not only a vegetable crop but also an alternative food crop against rice and wheat (Brown, 2005). Nutritionally, the tuber is rich in carbohydrates or starch and is a good source of protein, vitamin C and B, potassium, phosphorus and iron. Most of the minerals and protein are concentrated in a thin layer beneath the skin, and skin itself is a source of food fibre. Bangladesh has a significant agro-ecological potential of growing potato. The area and production of potato in Bangladesh has been increasing during last decades but the yield unit^{-1} area remains more or less static.The yield is very low in comparison to those of the other leading potato growing countries of the world, 40.16 t ha^{-1} in USA, 42.10 t ha^{-1} in Denmark and 40.00 t ha^{-1} in UK (FAO, 2019).Potato varieties cultivated during the winter in all the districts of Bangladesh.

Potato tuber quality is one of the most important quality attributes for consumers and industrial demand (Brown, 2005). Potato having optimum dry matter, specific gravity, reducing sugars, starch and good color are preferred by processing industry. The specific gravity and dry matter of potato tubers areinfluenced by type and amount of fertilizers, dates of planting and harvesting etc. (Burton and Longman, 1989). Abong *et al.* (2009) studied the storage and processing characteristics of red skinned, Kerr's pink, white skinned and Desiree potato varieties. Al though, potato product manufacturers are using High Yielding Variety (HYV), consumers in some parts of northern region of Bangladesh also prefer the local potato cultivars, because of taste, flavor, color, ambient storage ability local cultivars of potato.

There are many factors influenced on potato production, including planting date, varieties, weather conditions, nutrients and irrigation (Khalel, 2015).Also, potato plant is sensitive to the altering in the soil moisture content and the decrease of water stress that leading to a significant decrease in tubers quantity and quality. Current research study indicated that water havethe role in limiting potato production also be able to increase the rate of production by taking the best scheduled irrigation programs in the growing seasons of potato (Bhattacharjee *et al.*, 2014). The requirement for water irrigation of potato plants are diverse in different plant growth stages; tubers initiation and tubers bulking are the more sensitive stages in the plant growth life. In addition, more than 40% of world land is under arid or semi-arid climatic conditions (Ali and Talukder, 2008). The climate change has made the situation very difficult by dropping the rate of rainfall and therefore affected on the amount of water available for agriculture cultivation to get higher yield (Iglesias*et al.*, 2007). As a result of the limiting of water resources the full irrigation and using more water are not a strategic option in areas where water is the most limiting factor, more increasing in water productivity may be economically more affected for the farmer than obtaining high yields (Farooq*et al.*, 1990). The potato plants are required water irrigation depending on growth stage, which is tuber starting to produce and tuber bulking; both stages are sensitive in the growth of plant life (Abdallah, 1998). There are study confirm that decreasing in the rate of water irrigation leads to a significant reduction in leaf area and plant height (Hegazi and Awad, 2002). In addition, the percentage of dry mater in potato tuber and specific gravity were significantly increased with a reduction in water irrigation amount (Samey, 2006). Harvesting time can influence the biomass accumulation in potato tuber. The location, cultivar, date of harvest and tuber curing influences the physical and biochemical changes in the structural components of potato tissue during processing (Marwaha *et al.*, 2005). Early harvesting of tuber gives economic support to the farmers but it affects the quality. Tuber harvested at full maturity stage contains maximum dry matter and protein content and have higher specific gravities than immature ones (Misra *et al.*, 1993). Specific gravity is an important factor for maintaining quality tuber and is directly associated with the dry matter content (Marwaha *et al.*, 2005). High specific gravity potatoes are better suited for baking, frying, mashing and chipping (Haase, 2003; Pedreschi and Moyano, 2005). Potato product manufacturers prefer tubers of higher specific gravity than potatoes with lower specific gravity to get more chips (Haase, 2003). Color is also an important quality attribute which influences the acceptability of fried products (Nourian *et al.*, 2003). Golden yellow color is considered to be the best for high quality potato chips (De Freitas *et al.*, 2012). Specific gravity is positively correlated to dry matter and starch content in findings.

In Bangladesh, a local potato farmer has been lacking information on appropriate potato irrigation frequency and harvesting time. Hence, the present investigation was conducted to study the the effect of irrigation frequency and time of harvest on growth, yield and quality of potato with observing the following objectives-

OBJECTIVE

1. To know the most suitable irrigation frequency for maximum yield and batter quality potato production.
2. To select the most suitable harvesting time for better quality potato cultivars.
3. To study the combination effect of irrigation frequency and harvesting time on yield, specific gravity, dry matter content and processing of potato production.

CHAPTER II

REVIEW OF LITERATURE

Potato is an important cash crop of global significance. In Bangladesh recently, it has been drawn attention to improve yield and quality due to increasing its industrial demand. Very few information was available regarding the effect of irrigation frequency and time of harvest on growth, yield and quality of potato. Some of the pertinent works on these technologies reviewed in this chapter.

2.1 Effect of irrigation frequency on potato

Akkamis and Caliskan (2021) stated that the vegetative growth phase of potato plant begins with the sprouting of the seed piece and extends to stolon formation. Plant against water stress in this period, generally reduces the effect of water stress in later growth stages and improves tuber quality. Water stress during this stage decrease leaf area, root expansion, and plant height, and delays canopy development. During this period, the plant does not grow much, but maintain its development rapidly. Therefore, the water consumption of the plant is almost half of a mature plant. Excessive amount of water may cause the formation of exposed roots during this period. Thus, the amount of water to be given should not be more than the plant demand. In case of water is limited, tuber formation occurs earlier, but the number of tubers decreases. The researcher also mentioned that water stress can reduce the number of tubers plant^{-1} during tuber initiation period. However, this is not the same for all cultivars. Regular watering has a positive effect on tuber formation. Therefore, the plant needs the most water during tuber initiation period. If enough water is not given, plants can accelerate maturation. Tubers cannot reach the demand size and yield may decrease. In the drought condition, deformations may occur in the tubers. Hence, in case of insufficient water intake, tuber quality is adversely affected as well as yield.

Ayas (2020) and Çalışkan and Demirel (2018) stated from their research works that the soil of potato field must be moist for the seed tuber to emerge. However, the humidity level should not be excessive. The excess moisture in the soil during this period may result in the plant not being able to take in oxygen and therefore cause the tubers to decay. Irrigation should be done regularly and adequately. In conditions where the temperature is high, the soil temperature can be reduced by watering at short. Excessive irrigation or precipitation may cause irregular or no sprout emergence during this period. Excess moisture will also reduce tuber respiration by placing the seed piece under metabolic stress.

Eid *et al.* (2020) conducted two field experiments to investigate the effects of three drip irrigation regimes (G_1 = 120% crop evapotranspiration (ETc), G_2 = 100% ETc, and G_3: 80% ETc) and four nitrogen (N) source treatments (S_0 = non-fertilized; S_1 = urea, S_2 = ammonium nitrate and S_3 = ammonium sulfate on water consumption use, water utilization efficiency, chlorophyll, yield and tubers quality of potato (*Solanum tuberosum* L.; cv Diamond) under a drip irrigation system during two successive winter seasons (2015–16, and 2016–17)). The highest tubers yield was obtained from potato grown with G_1S_2 (65.8 Mg ha^{-1}), G_1S_3 (63.6 Mg ha^{-1}), G_2S_2 (64.1 Mg ha^{-1}) and G_2S_3 (62.4 Mg ha^{-1}), while the lowest tubers yield was obtained from potato grown with G_3S_0 (10.1 Mg ha^{-1}) and G_2S_0 (17.4 Mg ha^{-1}). Different treatments of N source resulted in a significant increase for water use efficiency (WU_tE) compared with unfertilized treatment. For the interaction effect, the highest WUtE was obtained from potato grown with G_3S_2 (18.1 kg m^{-3}), followed by G_3S_3 (17.6 kg m^{-3}), while the lowest WUtE was obtained from plants grown with G_3S_0 (3.0 kg m^{-3}). However, the highest chlorophyll content was obtained from plants grown with G_1 and any N source, followed by $G_2S_{1–3}$, while the lowest chlorophyll content was obtained from those grown with G_3S_0. The highest N, S protein, and P contents in tubers were obtained from plants grown with G_3S_3, G_3S_2, and G_2S_2, while the highest K content in tubers was obtained from plants grown with G_1S_1 and G_1S_2. In concussion, the integrative effects of G_1 or G_2 with S_2 or S_3 were recommended for high productivity, while the integrative effects of G_3S_3 and G_3S_2 were recommended for high quality tubers.

King *et al.* (2020) described that tuber initiation is the process in which the stolon leaves growing and the tip swells to twice the stolon diameter. It is particularly sensitive to water stress during tuber formation. In addition, water stress during tuber initiation period can reduce the specific gravity of potato tuber. On the other hand, the tuber bulking stage continues with a steady increase in tuber size and weight unless restrictive condition. Root growth improves, but the rise in total plant dry matter is considerably depend on tuber growth. Water stress at this stage often affects the total tuber yield more than the quality. Low humidity reduces or stops tuber growth during and after the stress period. So, it shortens tuber bulking period and can also led to internal and external defects in potato tuber. Excessive irrigation can inhibit physiological activity and nutrient uptake and may also reduce tuber growth by increasing disease susceptibility.

Wang *et al.* (2020) reported that potato tuber yield, largest tuber weight, commodity tuber weight, dry matter accumulation, and vitamin C content increased with the increase in the dripper discharge rate.

Elhani *et al.* (2019) demonstrated that tuber yield penalty was similar under partial root-zone drying compared to deficit irrigation. They reported a decrease in potato tuber sugar and protein content with the increase in water stress with higher values in partial root-zone drying than in deficit irrigation treatment. Adversely, the polyphenols and antioxidants amount increased in potato tubers with increasing water stress on potato plants. They also reported an increase in potato tuber protein content under the partial root-zone drying treatment and an increase in tuber polyphenols content with an increase in water stress. There was also higher metabolite content in potato tubers under partial root-zone drying than under deficit irrigation with less decrease in glucose and fructose concentrations and with double the amount of mannitol. In contrast, the researchers found that tuber content in glucose and fructose gradually decreased with decreasing seasonal water supply. These management approaches may be used by potato seed producers for increasing the number of potato seeds plant^{-1}.

Abdulrahman *et al.* (2018) carried out this study in two seasons (2017 and 2018) to evaluate the impact of irrigation interval on quality and tuber yield in potato cultivars. In this study there are four irrigation intervals (3, 5, 7 and 9 days) used by furrow irrigation method. The experimental plots were planted by potato by using four treatments (irrigation intervals); T1 = 3 days, T2 = 5 days, T3 = 7 days and T4 = 9 days). The analysis result of variance indicated that irrigation interval treatments significantly impacted the tuber production of potato. Generally, tuber yield significantly increased with increasing the rate of irrigation water. The application of 660 mm of irrigation water in T1 brought the highest tuber yield which recorded 38.4 and 40.73 t ha^{-1} of potato for consecutive 2 years of 2017 and 2018. However, the lowest tuber yield was recorded from the application of 316 mm of irrigation water in T4 which was 31.70 t ha^{-1} and 31.2 respectively in year 2017 and 2018. The reason for the yield reduction was referred to that of stolon non-formation which results in more tubers in the soil. Also, there were not substantial difference between 3-day interval (38.4 t ha^{-1}) and 5-day interval irrigation (37.16 t ha^{-1}) Irrigation increased the yield significantly, but the difference between the yield in 3day interval with 6 days interval was on the edge of significance. The highest yield followed after the most intense irrigation and was statistically significantly higher than the yield of the delay water irrigation. The fresh tuber of potato production was higher under high frequency of water irrigation than low frequency irrigation. With delayed irrigation the yield reduced significantly due to reduction in the availability of water. The potato tuber production in 3-day interval showed highest percentage of protein and starch content which were recorded the highest in both year of cultivation, but the abscisic acid was affected by more irrigation which in 3-day interval irrigation the rate was less than other. Also, in 5-day interval irrigation the rate was acceptable because there is no significant difference in terms of tuber yield, protein and starch content if compare with 3-day interval irrigation in particular for those area faced restricted in using water irrigation.

Gültekin and Ertek (2018) applied five different irrigation levels (I100, I85, I70, I55 and I40) in a two-year study in which they investigated the effect of water deficit practices on tuber development and quality. In the first year, the amount of irrigation water was between 243 mm and 311.9 mm, evapotranspiration was between 337.1 and 385.9, in the second year the amount of irrigation water was between 166.7 mm and 223.2 mm, and evapotranspiration was between 204 and 255.7. Yields ranged from 30.85 to 47.13 t ha^{-1} in the first year and between 28.77 and 44.45 t ha^{-1} in the second year. They reported that as the irrigation levels decreased, the number of tubers per plant, tuber weight, tuber diameter and length and marketable tuber ratio decreased, and the highest yield values and water use efficiency were obtained from I100 and I85 irrigation levels.

Ierna and Mauromicale (2018) conducted a two-year experiment where the combined effects of 3 irrigation levels [irrigation only at plant emergence, irrigation at 50% of maximum evapotranspiration (ETm) and irrigation at 100% ETm] and 3 N-P-K fertilization rates (low: 50, 25 and 75 kg ha^{-1}, medium: 100, 50 and 150 kg ha^{-1} and high: 300, 100 and 450 kg ha^{-1} of N, P_2O_5 and K_2O) on Etc (crop evapotranspiration), crop growth rate, aboveground dry biomass and tuber dry yield, sink/source (tuber yield/aboveground biomass yield) ratio, water productivity and crop drought response factor of potato were studied. Irrigation water amounts were 25 mm in plots irrigated only at plant emergence in both years, 87 and 96 mm in plots irrigated at 50% of ETm, 174 and 192 mm in plots irrigated at 100% of ETm, respectively in the two years. Irrigation based on 100% of ETm + high rate of N-P-K fertilization proved the best combination to promote ETc, crop growth, and improve aboveground biomass, tuber yield, and sink/source ratio but not WP. Fertilization played a crucial role in enhancing water productivity of this crop especially in plots irrigated only at plant emergence, where both low and medium fertilization rates allowed maximizing WP (2.3 kg m^{-3} dry weight) ensuring an acceptable tuber yield (about 3.7 t ha^{-1} dry weight). These results are of considerable importance to farmers to achieve more efficient and rational use of water by potato grown in very limited water availability environments.

Comparing deficit irrigation and partial root-zone drying with full irrigation, El-Abedin *et al.* (2017) found that the deficit treatment and partial root-zone drying decreased potato fresh and dry tuber yield compared to the full irrigation with no difference between the treatments for the number of marketable size tubers while the number of oversized tubers was significantly lower under the partial root-zone treatments than under the full irrigation treatment. They indicated that the highest number of tubers per plant was obtained under full irrigation treatment and the deficit irrigation at 50% of the full irrigation treatment produced 51%, 72.8%, and 136.9% more tubers than the deficit irrigation at 70%, partial root-zone drying at 70% and partial root-zone drying at 50%, respectively.

Camargo *et al.* (2015), Fleisher (2008), Steyn *et al.* (1998), Lahlou and Ledent (2005) and Kashyap and Panda (2003) mentioned from their separate research works that that fresh potato yield and total dry matter accumulation increased with water supply.

Camargo *et al.* (2015) suggested that applying 80% to 100% of irrigation requirements helped to achieve high biomass accumulation in potato. They also reported that 80% of irrigation requirements showed statistically similar yields to 100% and 120% of irrigation requirements in potato field.

Byrd *et al.* (2014) showed the potential for reduced irrigation management for sustainable potato production in Florida.

Karam *et al.* (2014) during a two-year experiment found that the full irrigation treatment was required to overcome deficit irrigation at tuber bulking and tuber ripening by 12 and 43%, in the first year and 11 and 39% in the second year, respectively. The reserachers reported that 50% of tuber yield was constituted with the large size potatoes (> 200 g) under the full irrigation treatment while that proportion was 48% under the deficit irrigation at tuber bulking and 46% under deficit irrigation at tuber ripening. A larger number of small tubers was obtained when deficit irrigation was applied during the tuber bulking stage compared to the tuber ripening state. They found a 12% and 42% reduction in potato marketable yield when deficit irrigation was imposed at tuber bulking and tuber ripening, respectively, compared to the well-irrigated treatment.

Carli *et al.* (2014) reported that both dry matter and starch content in potato increased with water restriction.

Peerzada *et al.* (2013) evaluated four different irrigation frequencies viz., no irrigation, and irrigations at 07, 14- and 21-days intervals, for their effect on development of late blight of potato cv. kufri Jyoti in field trials. Irrigation frequencies have marked effects on the incidence, intensity and yield of the potato crop. In the cropping season 2007,the maximum tuber yield (145.22–164.26 q ha^{-1}) with better percentage of grade A (24.51–25.86%) and B (50.00–55.48%) tubers were obtained in treatments receiving irrigation at 14–21 days intervals. The plots receiving irrigation at 7 days interval yielded statistically similar yield compare to check plots receiving no irrigation. The maximum tuber yield (164.26 q ha^{-1}) were observed in plots receiving the least frequent irrigation at 21 days interval followed by those receiving irrigation at 7–14 days interval (115.74–145.22 q ha^{-1}). In the cropping season 2008,the maximum tuber yield (143.10–159.60 q ha^{-1}) with better percentage of grade A (23.00–25.61%) and B (55.81–60.35%) tubers were obtained in treatments receiving irrigation at 14–21 days intervals. The plots receiving irrigation at 7 days interval yielded statistically similar yield compare to check plots receiving no irrigation. The maximum tuber yield (159.60 q ha^{-1}) were observed in plots receiving the least frequent irrigation at 21 days interval followed by those receiving irrigation at 7–14 days interval (122.38–143.10 q ha^{-1}). The un-irrigated plots exhibiting minimum tuber yield (112.90 q ha^{-1}). The A grade tubers were maximum (25.61%) in plots receiving 21 day irrigation followed by (23.00–19.12%) those of receiving irrigation at 7 and 14 days interval.

Ballmer *et al.* (2012) reported that water restriction reduced the starch content of potato tubers.

Sahebi *et al.* (2012) stated that there was no significant change in starch content of potato tubers with irrigation. They recorded that starch content greatly enhanced with water limitation compared to control.

Ierna *et al.* (2011) conducted a 2-year with the aim of achieving an appropriate combination of irrigation water and nutrient application in cultivation management of a potato crop. The combined effects of 3 levels of irrigation (irrigation only at plant emergence, 50% and 100% of the maximum evapotranspiration – ETM) and 3 levels of mineral fertilization (low: 50, 25 and 75 kg ha^{-1}, medium: 100, 50 and 150 kg ha^{-1} and high: 300, 100 and 450 kg ha^{-1} of N, P_2O_5 and K_2O) were studied on the tuber yield and yield components, on both water irrigation and fertilizer productivity and on the plant source/sink (canopy/tubers dry weight) ratio. The results showed a marked interaction between level of irrigation and level of fertilization on tuber yield, on Irrigation Water Productivity and on fertilizer productivity of the potato crop. The researchers found that the treatments based on 50% ETM and a medium level of fertilization represent a valid compromise in early potato cultivation management. Compared to the high combination levels of irrigation and fertilization, this treatment entails a negligible reduction in tuber yield to save 90 mm ha^{-1} $year^{-1}$ of irrigation water and 200, 50 and 300 kg ha^{-1} $year^{-1}$ of N, P_2O_5 and K_2O, respectively, with notable economic savings for farmers compared to the spendings that are usually made.

Sharafzadeh *et al.* (2011) conducted a field experiment to evaluate the effects of irrigation regimes, every fourth day as control (I_c), every day (I_1), every second day (I_2) and every sixth day (I_6) and two cultivars, Picasso (P) and Santea (S) on growth and yield of the potato. The results indicated that the maximum shoot height (74.53 cm) was achieved on I_1P. The highest stolon number (7.17) was obtained in I_1P. Stolon length was the maximum (4.78 cm) in I_1S. The maximum tuber number per plant (6.90) was shown in I_1P. The highest total tuber weight (714.67 g $plant^{-1}$) was achieved on I_1P.

Badr *et al.* (2010) mentioned potato as a very sensitive plant to water shortage in the soil. The highest efficiency was obtained when the usable water in the soil is in the range of 30–50%. If the moisture level in the soil drops below 50%, the yield may decrease. Potatoes are significantly affected by water deficiency during germination, tuber formation and tuber growth periods, while they are less sensitive to water during maturation and early vegetative periods. Potatoes need frequent irrigation for good growth and yield. Yield is significantly affected by storage quality, disease resistance and duration, rate, frequency of irrigation. Variable irrigation level has a significant impact on yield and yield components in potatoes. Hence, applying less water than necessary may cause a decrease in the yield value. If irrigation is applied fully in potatoes, the yield will be at the highest value. However, if the water applied in underground drip irrigation is 80% ETc, yield values similar to the full irrigation conditions applied in above-ground drip irrigation can be obtained. Therefore, it is seen that 20% of irrigation water can be saved in potatoes.

Jensen *et al.* (2010) reported that 30% was the water-saving limit compared to the field capacity in potato field.

Brocic *et al.* (2009) reported yield reduction of potato cultivar Liseta under 70% partial root-zone irrigation and silty–clay soil compared to the full irrigation.

Kempenaar and Struik (2007) stated that after wine kill, tuber specific gravity of potato decreased with desiccation.

Nagaz *et al.* (2007) stated that there was a decrease in tuber number and weight as a result of water scarcity during the formation and development of potato tubers.

Darwish *et al.* (2006) reported that restricted irrigation reduced tuber dry matter production and average weight of commercial tuber in potato. Irrigation can have a direct impact on yield and yield components. Dry matter content in tuber increases with 60% and 100% full irrigation but decreases at 120% of full irrigation.

Kiziloglu *et al.* (2006) reported that potato for suitable growth and optimum yield needs frequent irrigation.

Wang *et al.* (2006) studied the effect of irrigation frequency on soil water distribution, potato root distribution, potato tuber yield and water use efficiency in 2001 and 2002 field experiments. Treatments consisted of six different drip irrigation frequencies: N_1 (once every day), N_2 (once every 2 days), N_3 (once every 3 days), N_4 (once every 4 days), N6 (once every 6 days) and N_8 (once every 8 days), with total drip irrigation water equal for the different frequencies. The results indicated that drip irrigation frequency did affect soil water distribution, depending on potato growing stage, soil depth and distance from the emitter. Under treatment N_1, soil matric potential (cm) Variations at depths of 70 and 90 cm showed a larger wetted soil range than was initially expected. Potato root growth was also affected by drip irrigation frequency to some extent: the higher the frequency, the higher was the root length density (RLD) in 0–60 cm soil layer and the lower was the root length density (RWD) in 0–10 cm soil layer. On the other hand, potato roots were not limited in wetted soil volume even when the crop was irrigated at the highest frequency. High frequency irrigation enhanced potato tuber growth and water use efficiency (WUE). Reducing irrigation frequency from N1 to N8 resulted in significant yield reductions by 33.4% and 29.1% in 2001 and 2002, respectively. For total ETc, little difference was found among the different irrigation treatments.

According to Antal *et al.* (2005), the number of potato plants per unit area should be increased by 10–15% by irrigation. For yields higher than 40 t ha^{-1} and for superior quality, continuous and regular irrigation is necessary.

Islam (2005) tested the variety of potato Diamant for yield and disease infestation under different irrigation intervals and quantities. Three irrigation intervals i.e. 7, 12 and 17 days along with three levels of water quantities equalling 50, 100 and 150% of depleted soil moisture were used for determining the extent of yield and scab disease on the selected potato variety. The treatments were as follows: T_1 = Irrigation at 7 days interval and amounting 50% of depleted soil moisture, T_2 = Irrigation at 7 days interval and amounting 100% of depleted soil moisture, T_3 = Irrigation at 7 days interval and amounting 150% of depleted soil moisture, T_4 = Irrigation at 7 days interval and amounting 50% of depleted soil moisture, T_5 = Irrigation at 12 days interval and amounting 100% of depleted soil moisture, T_6 = Irrigation at 12 days interval and amounting 150% of depleted soil moisture, T_7 = Irrigation at 17 days interval and amounting 50% of depleted soil moisture, T_8 = Irrigation at 17 days interval and amounting 100% of depleted soil moisture and T_9 = Irrigation at 17 days interval and amounting 100% of depleted soil moisture. From the study, it was observed that irrigation at an interval of 12 days and watering up to 100% of depleted soil moisture produced the highest fresh yield (24.64 tons ha^{-1}) whereas irrigation interval of 7 days and watering up to 150% of depleted soil moisture produced the lowest fresh yield (21.68 tons ha^{-1}) of potato. The highest total yield of potato (27.89 tons ha^{-1}) were obtained in treatments, irrigated at 12 days interval and watered up to 100% of depleted soil moisture, whereas irrigation interval of 7 days and watering up to 150% of depleted soil moisture produced the lowest total yield (25.98 tons ha^{-1})

of potato. Considering fresh yield, total yield and water use, 12 days irrigation interval and watering up to 100% of depleted soil moisture appeared to be the most suitable for the variety of potato Diamant.

Karam *et al.* (2005) mentioned that potato growth, yield, and yield component are affected by irrigation regimes mostly tuber bulking and ripening which are the water stress-sensitive stages.

Önder *et al.* (2005) mentioned that since potato are great sensitive to moisture deficit in the soil, the available water in the soil should not decrease below 65% in order to obtain the highest yield.

Jensen *et al.* (2004) observed that water stress in potato improved the chip quality due to the higher content of tuber dry matter.

Shock (2004) and Thornton (2002) reported that all growing stages of potato, especially tuber formation stage are very sensitive to water deficit stress.

Yuan *et al.* (2003) stated that the duration when potatoes need water the most is the period from the beginning of tuber formation to 15 days before harvest. At this stage, if irrigation is not applied regularly, it can cause secondary growth. Irrigation increases the average tuber weight but does not always increase the number of tubers per plant. They reported that potato fresh tuber and marketable yield increased with increasing irrigation regimes. The researchers also indicated that specific gravity of potato tended to decrease with increasing irrigation depth.

Hassan *et al.* (2002) concluded that the stolonization and tuberization stages of potato were more sensitive to irrigation than bulking and tuber enlargement stages.

Shock and Feibert (2002) observed that under deficit irrigation conditions, potato yield and grade responded linearly to applied water. The researchers concluded that a short period of water stress following tuber set reduces tuber yield and quality of potato.

Deblonde and Ledent (2001) reported a 17% reduction in potato tuber number of six cultivars affected by water stress, with no impact on the yield due to compensation by average tuber dry weight.

Fabeiro *et al.* (2001) reported potato yield reduction under deficit irrigation during potato growth, tuber bulking, and ripening stages while the larger tubers were obtained under the fully irrigated potato and the ripening stage deficit irrigation, and the smallest tubers were obtained under the applied deficit irrigation during the growth period with a high tuber number per plant.

Arends (1999) observed that the lack of water during the period of tuber set and development in potato field had a disadvantageous effect on the distribution of tubers between the different size categories: the ratio of large tubers is reduced. According to his results, the adverse effect of water deficiency is stronger on loose and heavy soils than on mid-heavy loam soil.

Iqbal *et al.* (1999) reported that the potato growing stage is the least sensitive to water stress.

Porter *et al.* (1999) found that potato tuber specific gravity decreased with increasing irrigation rates.

Waddell *et al.* (1999) reported that the specific gravity of potato tubers from the relatively stressed treatments was significantly lower than the specific gravity of tubers from the well-irrigated treatment under sprinkler irrigation.

Allen *et al.* (1998) reported that for an efficient potato production, irrigation should be done before 35% of the total available moisture is consumed and effective root depth should be taken as 0.4 m in irrigation.

Kruppa (1998) mentioned that in developing potato production, the exact knowledge of production factors (ecological, biological and agrotechnical), their exploration and the application of cultivar-specific technologies are of special importance, in addition to the improvement of efficacy, the better utilization of opportunities of the technologies and the biological bases, irrigation can increase yields considerably: the temporary periods of water deficiency can be prevented and the amount and quality of yield are enhanced.

Shock and Feibert (1998) mentioned that the proper irrigation management after tuber initiation increases the size of tubers of potato.

Shock *et al.* (1998) and Hang and Miller (1986) indicated that deficit irrigation trended to decrease tuber specific gravity of potato.

Karafyllidis *et al.* (1996) recorded the highest potato yield under 65% of maximum evapotranspiration.

Foti *et al.* (1995) reported no significant yield difference between 100% and 66% of maximum evapotranspiration irrigation regimes on potato tuber yield while they obtained the highest tuber yield with 133% maximum evapotranspiration water supply.

Cappaert *et al.* (1994) stated that potato tuber number per plant and total yield increase with adequate irrigation water management before and during tuber initiation.

Harris (1992) observed that early appropriate stages irrigation increased tuber dry matter and continuous or late-season irrigation reduced potato dry matter content.

Silva *et al.* (1991) reported reduction in potato tuber specific gravity associated with late-season irrigation.

Harun-ur-Rashid *et al.* (1990) found when studying the relationship between the water use of irrigated potato and potato yield that if 40 mm water was given in 12 days (irrigation was started 30 days after planting), the highest number of the tubers were in the size categories of 28–45 mm and larger than 45 mm. The highest ratio of tubers below 28 mm was found in the non-irrigated treatment.

Miller and Martin (1990) reported that daily irrigation improved total tuber yield, the number of tubers and increased the potato specific gravity compared to four-day interval irrigation.

Wright and Stark (1990) reported that in case of potato cultivation, some stress can be tolerated during early vegetative growth and late tuber bulking under water deficit condition.

Lelkes (1988) showed that the average total tuber yield of potato without irrigation ranged between 7 and 50 t ha^{-1}. The average yield was 28 t, 80% of which reached the table size. With proper irrigation, yields of 40–47 t ha^{-1} were obtained with the average yield being 43.5 t ha^{-1}. The yield increment due to irrigation was 15.5 t ha^{-1}. The favourable effect meant not only a yield increment, but also a significant reduction in the variation in yield between the years. Under non-irrigated conditions, especially in dry years, the ratio of small tubers was 40–50%, under irrigated conditions with a proper water supply, this ratio was below 25%, it was even less than 10% for some cultivars. Under good water supply or due to irrigation, the ratio of undersized tubers decreases and the ratio of marketable tubers increases. No significant differences were found in the number of tubers.

Drewitt (1970) reported an increase in specific gravity of potato tuber with an increase in irrigation frequency.

Peterson and Weigle (1970) indicated that tuber specific gravity of potato increased under mist irrigation conditions.

Singh (1969) stated that for potato production sustainability, moisture should be kept above 50% of the total available water of the site soil.

2.2 Effect of harvesting time on potato

Haque (2016) conducted an experiment to evaluate the yield and quality of potato as influenced by harvesting time and their subsequent storage period. The experiment consisted of two factors, i.e., Factor A: Potato varieties; V_1 = Asterix, V_2 = Lady Rosetta, V_3 = Courage, V_4 = Diamant and V_5 = BARI TPS-1; Factor B: Time of harvest; i.e., H_1 = Harvest at 80 days after planting (DAP), H_2 = Harvest at 90 DAP, H_3 = Harvest at 100 DAP and H_4 = Harvest at 110 DAP. The present study revealed that harvesting time had significant effect on most of the yield and quality contributing parameters, except specific gravity. Results demonstrated that yield (total yield, marketable yield and seed yield) gradually increased with increasing harvesting time up to 100 DAP and there after yield remained statistically similar. On the other hand, some quality parameters viz. dry matter, firmness, glucose content, starch content increased with increasing harvesting age but total soluble solid (TSS) and sucrose content decreased with increasing harvesting time. Among the twenty treatment combinations, Asterix which was harvested at 100 DAP produced the maximum yield (35.55 t ha^{-1}) but Courage which was harvested at 110 DAP showed the highest dry matter content (24.85%), glucose content (0.75 mg g^{-1} FW) and starch content (21.84 mg g^{-1} FW).

Rymuza *et al.* (2015) undertook a three-year study to assess the effect of ridge height and harvest date, determined based on soil temperature, on edible potato tuber quality. The following factors were examined: edible potato cultivar (factor A): Sante, Romula, Żagiel; Ridge height (factor B): low ridge (16 cm), standard ridge (20 cm), high ridge (24 cm); harvest date determined based on soil temperature (16, 12 and 8°C) averaged over 3 consecutive days before potato tuber harvest, measured at the depth of 10 cm at 8 o'clock in the morning. Environmental conditions during the growing season, cultivar, and harvest date had a substantial influence on dry matter and starch contents as well as cooking attributes of potato tubers. Starch and dry matter contents were affected by the study years, cultivar and harvest date, the highest levels being found for cv Romula tubers as well as tubers harvested at the soil temperature of 12°C. CvSante tubers and tubers harvested at the soil temperature of 12°C, whether raw or cooked darkened the least.

Bhattacharjee *et al.* (2014) set up an experiment at laboratory to study the influence of variety and date of harvesting on post-harvest physiology of potato derived from TPS at ambient storage condition. The experiment consisted of 2 factors; Factor A: Potato variety, V_1 = BARI TPS-1, V_2 = BARI TPS-2, V_3 = HPS-364/67 and V_4 = Lady Rosetta; Factor B: Time of harvest viz. D_1 = 80 DAP, D_2 = 90 DAP, D_3 = 100 DAP and D_4 = 110 DAP. All post-harvest losses except apical sprout length decreased with increasing the time of harvest. Specific gravity, reducing sugar, total sugar and starch content increased with advancing storage period, whereas non-reducing sugar decreased with increasing storage period. At before storage and 20, 40, 60, 80 and 100 DAS (days after storage), the highest dry matter in flesh (16.31, 16.90, 17.07, 18.41, 20.39 and 20.71%) was observed from D_4 . At 20, 40, 60, 80 and 100 DAS, the minimum weight loss (4.64, 6.20, 9.58, 13.24 and 14.99%) was recorded from D_4 . At 20, 40, 60, 80 and 100 DAS, the minimum percentage of rotten tubers (1.72, 2.54, 4.18, 5.10 and 7.18%) was recorded from D_4. The maximum days to start of sprouting (48.83) was observed from $D_{4.}$ The longest apical sprout length (1.84 cm) was observed from D_4. The maximum days to start of rotting (18.33) was observed from D_4. The maximum days to start of shrivelling (87.08) was observed from D_4. The maximum days to 80% shrivelling (150.17) was observed from D_4. At harvest and 100 DAS, the highest specific gravity (1.12 and 1.14) was observed from D_4 and D_2, while the lowest specific gravity (1.08 and 1.11) was recorded from D_4, respectively for same data recording. At harvest and 100 DAS, the highest reducing sugar (0.29% and 0.59%) was observed from D_1, while the lowest reducing sugar (0.25% and 0.45%) from

D_4. At harvest, the highest non-reducing sugar (0.30%) was observed from D_4, while the lowest non-reducing sugar (0.21%) from D_4. At 100 DAS, the highest non-reducing sugar (0.23%) was observed from D_1, while the lowest non-reducing sugar (0.18%) from D_1. At harvest and 100 DAS, the highest total sugar (0.59% and 0.78%) was observed from D_4, while the lowest total sugar (0.46% and 0.67%) from D_1, respectively for same data recording days. At harvest and 100 DAS, the highest starch content (18.22% and 20.03%) was observed from D_1, while the lowest starch content (17.25% and 18.86%) from D_4, respectively for same data recording days.

Chowdhury (2014) conducted a field experiment to find out the effect of harvesting time on yield and some processing quality of local potato cultivar. Comparative study of some processing traits of three local varieties of potato (‘Fata Pakri’, ‘SadaPakri’ and ‘Rumana’) harvested at 80, 90, 100 and 110 days after planting with those of True Potato Seed variety ‘BARI TPS-1’ is used in this study. Potato tuber yield increased significantly up to the last date of harvest. Mature tubers exhibited significantly higher dry matter and specific gravity compared to immature ones. Tuber color was also significantly affected by time of harvest irrespective of varieties.

Amin (2012) conducted a field experiment to investigate the effect of seed tuber size and harvesting time on morpho-physiological characters, yield attributes and yield of potato. The experiment comprised of four different size of seed tubers *viz*., 28– < 45 mm, 20– < 28 mm, 10– < 20 mm and < 10 mm and four harvesting time *viz*., 70 days after planting (DAP), 80 DAP, 90 DAP and 100 DAP. Results showed that stems and leaves hill^{-1}, LA, TDM and tubers hill^{-1}, single tuber weight and tuber weight plot^{-1} increased with increasing time of harvest up to 90 DAP. The highest number of stems and leaves hill^{-1}, LA, TDM, tubers hill^{-1}, single tuber weight and tuber weight plot^{-1} were observed in the harvesting time at 90 DAP and the lowest in harvesting time at 70 DAP. However, the highest gross tuber yield ha^{-1} was observed in the harvesting time at 90 DAP and the lowest was recorded in 70 DAP.

Dehdar *et al.* (2012) conducted this project for determining the effects of planting and harvesting dates to obtain maximum potential yield of two potato cultivars (Caesar and Agria). In this experiment, main plots included two cultivars (Caesar and Agria), sub-plots included two planting dates (4 May and 5 June) and sub-sub plots included four harvesting dates (1 September, 16 September, 6 October and 21 October). The result showed that cultivars, planting and harvesting dates influenced tuber yields (ton ha^{-1}), no of tuber per plant, no of main stems and mean yield of single plant (g) significantly. According to this study, tuber yield and mean yield of single plant was at the pick when potatoes harvested in 1 September (the earliest harvesting time that tested in this study). There were significant differences between September and October harvest in number of tubers per plant and main stems per plant as well. Late harvest coincides to autumn rainfall contributing to increasing disease and harvesting problems. Furthermore, these late harvested potatoes have short shelf life in view of not developed subrinization. Because of these reasons and based on the results, early harvesting in September is the best time for harvest of potato tuber in comparison with October.

Elfnesh *et al.* (2011) reported that specific gravity and dry matter content increased with the maturity of tuber and usually crops those have more time to mature, produce tubers with high specific gravity and dry matter content.

Khan *et al.* (2011) carried out a field trial to optimize the sowing date and crop growth period of potato. The tubers were planted on four dates with one-week interval starting from September 24 in 2004. Tubers planted at each sowing date were harvested on six different dates starting from week-10 and ending at week-15. Harvesting potato at various intervals affected different yield and quality parameters significantly. Total number of tubers, percent larger and medium sized tubers, tuber yield and plant dry bio-mass increased with the delay in harvesting. However, dry matter in tuber was found higher at earlier harvestings.

Mehta *et al.* (2011) studied on four Indian processing and one exotic potato variety harvested directly at 10-day interval between 70 and 100 days after planting and at 120 days after 20 days of tuber skin curing in the soil following dehaulming which were evaluated for French fry quality. Tuber dry matter increased with maturity and was > 20% at 90 days after planting in Kufri Chipsona-1, Kufri Chipsona-3 and KufriFrysona and at 100 days in Kufri Surya. Reducing sugar content was low (< 100 mg/100 g fresh weight), except in Kennebec (172 mg/100 g fresh weight) harvested at 100 days after planting. Sucrose content decreased significantly towards crop maturity and curing.

Söğüt and Öztürk (2011) investigated the effect of harvesting time on yield and quality traits for spring season production in different maturing potato (*Solanum tuberosum* L.) cultivars. 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 t 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. Tuber yield increased from 8.9 to 17.2 t ha^{-1} and from 9.2 to 18.8 t ha^{-1} in 2006 and 2007, respectively, when harvesting was delayed from 75 to 120 days from planting. At the first harvest, (75 DAP) tuber yield was lower than 105 and 120 DAP. Tuber yield increased with the progress of growth and maturing of the tuber. Similarly, mean tuber fresh mass increased from 37.5 to 80.3 g in 2006, from 35.7 to 85.3 g in 2007 as harvesting was delayed. The results indicate that the tuber fresh mass increased significantly with incremental increase in harvesting time. At the earliest harvest, (75 DAP) the average tuber fresh mass was 37.5 and 35.7 g in 2006 and 2007, respectively. The tuber fresh mass increase during the last 15 days (105 to 120 DAP) was 21.4 and 28 g in 2006 and 2007, respectively, resulting in average tuber fresh mass of 80.3 and 85.3 g in 2006 and 2007, respectively. Tuber number per plant also changed significantly with time of harvest, their highest tuber number was attained when plants were harvested after 120 days of planting. Tuber number per plant data revealed significant increase with extension in harvest time. The lowest tuber number of 3.8 plant^{-1} (in 2006) and 4.2 plant^{-1} (in 2007) in this experiment was recorded at 75 DAP. There was an incremental increase in tuber number when crop was allowed in the field for longer growth period. Results showed that, tuber number at 120 DAP was significantly more than the tuber number obtained in 75 DAP. However, tuber number at 75, 90 and 105 DAP was non-significantly different. Differences in dry matter concentration among harvesting time were minor between 90 and 120 DAP, but the highest dry matter percentage were observed at 105 DAP with 23.5% and 23.4% in 2006 and 2007, respectively. Delaying harvest until 105 DAP resulted in greater specific gravity. However, the results indicated that tuber specific gravity decreased in late harvesting time (120 DAP), which were harvested at warmer part of the season, showing that cooler temperatures during harvesting time is more crucial to the tuber specific gravity under warmer condition. The results showed that, like other parameters, starch content also varied significantly with harvesting time. It was higher when the crop harvests delayed to 105 DAP. The highest starch content was recorded at 105 DAP in both years (14%). When the crop is harvested at 75 DAP, the starch content decreased significantly with incremental decrease in harvest time so that at 75 DAP, it decreased to 13.2% and 13.1% in 2006 and 2007, respectively. Since potato tubers are storage organs, the results indicated a reasonable trend of starch accumulation as harvesting is delayed from 75 to 105 DAP (Ali *et al.*, 2003). The starch content of 13.2% (in 2006) and 13.1% (in 2007) at 75 DAP, gradually increased to 13.6% and 14.0% at 90 and 105 DAP. However, the difference in starch content between 90 and 105 DAP was nonsignificant. Starch content decreased after 105 DAP. Thus, harvesting on mid-June (105 DAP) resulted in higher specific gravity and starch content over crop harvest on late-June (120 DAP). This data suggested that, tuber dry matter accumulation was affected by late harvesting time which led to reduction in dry matter accumulation as a result of slow growth at high temperatures. The optimal range for tuber growth is 15 to 20°C and as temperatures rise to 27°C, tuber dry matter percentage decrease (Yamaguchi *et al.*, 1964).

Abong *et al.* (2009) experimented on Kenyan potato cultivars to observe the influence of potato cultivar and stage of maturity on chips and French fries. Dry matter content ranged from 19.50% to 24.07% and 20.56 to 24.66% in clone 393385.39 and variety Dutch Robyjn for tubers harvested 90 and 120 days after planting, respectively.

Ierna (2009) investigated the influence of potato variety and harvest date on tuber nitrate content for off-season production in three varieties: Arinda (mid-early), Spunta (mid-late) and Mondial (late). Samples of tubers were harvested at 90, 105 and 120 days after planting in winter–spring crop and at 80, 95 and 110 days after planting in summer–autumn crop. After a delay of the harvest date, nitrate contents in the investigated tuber samples significantly decreased in winter–spring crop, whereas they increased in summer–autumn crop in the three potato varieties, but to the greatest extent in the case of late Mondial variety.

Kushwah and Singh (2008) conducted an experiment during to evaluate the effects of intra-row spacing (10.0, 12.5, 15.0, 17.5, 20, 22.5 and 25.0 cm) and haulm cutting date [60, 65, 70, 75 and 80 days after planting (DAP)] on the production of small-sized tubers of potato. Intra-row spacing of 25 cm and haulm cutting at 80 DAP recorded the highest values for plant height, stems per plant, fresh haulm weight, tuber yield per hectare and NPK content of soil as well as the highest net returns and benefit ∶ cost ratio.

Lisińska (2006) reported that the delayed harvest results in increased dry matter contents of potato.

Bashir *et al*. (2005) conducted an experiment to determine the effect of altitude (at 1959 m and at 1424 m above sea level) and harvesting date (80, 90, 100 and 110 days after planting) on the yield and quality of seed potato (cv. Desiree). In harvesting time of 110 days after planting, maximum weight of medium (4.2 kg) and large size tubers plot^{-1} (26.2 kg), total yield ha^{-1} (45.2 t) were recorded and seed tuber yield ha^{-1} (6.5 t) were the maximum in harvest at 100 days after planting.

Chang *et al*. (2005) set up an experiment to investigate the growth patterns of potato cultivar 'Superior', including tuber number, size and quality under hydroponics. Potato tubers were sampled at 60, 70, 80 and 90 days after transplanting (DAT). Specific gravity increased with the tuber size up to 10 g, but the difference between 10 and 50 g tubers was not significant. The specific gravity increased over time to 90 DAT. Shoot growth was maximum at the early harvesting date (60 or 70 DAT) and declined thereafter. Except for tubers from 60 DAT, the dormant period of early harvest tubers was not different with that of late harvest tubers of 90 DAT. These results clearly represented an economic advantage of early harvesting of 70 or 80 DAT because of cost reduction in hydroponics.

Marwaha *et al*. (2005) investigated tuber yield, processing quality and changes in the processing and nutritional characteristics, such as dry matter, reducing sugars, sucrose, soluble protein, free amino acids and total phenols in the tubers of five Indian potato varieties including two processing and three table varieties and five American processing cultivars. Samples were harvested at 10-day intervals commencing on 13 December, 60 days after planting, till 90 days. Yield increased significantly up to the last date of harvest and the mature tubers displayed significantly higher dry matter, free amino acids and total phenols but lower levels of reducing sugars and sucrose and produced chips with better colour appearance.

Tamiru (2005) conducted a field study by involving potato varieties Al-111 and Al-624 with four population densities (88 888, 66 666, 44 444 and 33 333 plants ha^{-1}) 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. A plant population of about 88,888 plants ha^{-1} and harvesting at 90th day after planting (DAP) promoted production of maximum dry matter yield per unit area, irrespective of varieties studied.

Rytel (2004) stated that delayed harvest resulted in increased dry matter contents of potato but the rate of their accumulation depends on cultivar and growing conditions.

Ali *et al*. (2003) reported that dry matter content and specific gravity of potato tubers increased when harvesting was delayed to the optimum time.

Mehta and Kaul (2003) evaluated the storability and processing quality of two potato cultivars cv. Kufri Chandramukhi and Kufri Lauvkar and found that the respiration rate one day after harvest was the highest in immature tubers harvested at 60 DAP, and the rates decreased as the harvest was delayed. The weight loss in stored potatoes was affected by harvest date with more physiologically immature tubers.

Ravichandran and Singh (2003) conducted field trials to investigate suitable agro-techniques for obtaining the maximum number of seed size tubers from potato cultivars Kufri Swarna and Kufri Jyoti. Treatments included: tuber weights of 10–20, 20–30, 30–40 and 40–50 g; intra-row spacing of 10, 15 and 20 cm; and 2 dates of haulm killing (75 and 90 days after planting). The authors observed that in both cultivars, 30-50 and 20-50 g tubers, may be used at an intra-row spacing of 10 cm, and with haulm killing at 90 days after planting to obtain the maximum number of seed size tubers.

Waterer (2002) studied the influence of planting and harvest dates on yields and grade-out due to tuber damage by common scab (*Streptomyces* spp.) over three cropping seasons using two cultivars of potato 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. The researcher demonstrated that common scab of potato may be managed by minimizing the period of the crop in the ground, but 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.

Kim *et al*. (1998) conducted a study to investigate the relationship between harvesting date and deterioration rate, sprouting rate and the sugar, protein and ascorbic acid contents of potato cv. Dejima, Gosi#1 and Gosi#5 tubers. Potatoes were harvested 90, 120, 150, 180, 210 or 240 days after planting. No differences in deterioration rate and sprouting rate were observed between cultivars, but these factors increased when tubers were harvested 180, 210 or 240 days after planting. Total sugar and crude protein contents remained constant until 180 days after planting, but reduced thereafter, total sugar and crude protein content at 240 days after planting being reduced by 3% and 0.2% compared to that at 90 days. Vitamin C content was reduced by 3–4 mg at 240 days after planting. Mineral composition (Ca, P, K, Fe) exhibited a tendency to be reduced when the harvesting time was delayed.

Marwaha (1998) observed an increase in the specific gravity of potato tubers with the increase in harvesting time.

Jeong *et al*. (1996) carried out an experiment in order to select cultivars suitable for processing and determine the optimum harvesting time for the potato cultivars suitable for cultivation. Potato tubers from six cultivars were harvested 80, 90, 100 and 110 days after planting. All cultivars showed a gradual increase in specific gravity, dry matter content and starch content of potato tubers until 100 days after planting, and showed a decrease thereafter. Reducing sugar content showed the reverse tendency of changes. In spite of the slight difference among cultivars, the highest crisp colour value was obtained 90 to 100 days after planting.

Sinha *et al.* (1992) grew potato cvs. Atlantic, Eramosa, Kanona, Norchip, Onaway and Saginaw Gold, and selections MS 700-70, MS 700-83 (Spartan Pearl), MS 716-15 and W-855 (Snowden) on a sandy loam in Michigan. In year 1988, average yields were 46.90 t ha^{-1} at 98 days and 54.70 t ha^{-1} at 138 days; corresponding yields in 1989 were 43.10 t $ha^{-1}$and 52.30 t ha^{-1}. Increase in yield between the two harvest dates ranged from 0–19.6 t ha^{-1}. Tuber yield after 138 days was the highest for 'MS-700-83' (62.30 t ha^{-1}) in 1988 and 'MS-700-70' (59.40 t ha^{-1}) in 1989 and the lowest in 'Eramosa' in both years (41.20 and 43.00 t ha^{-1} in 1988 and 1989, respectively). Two of the cultivars, Onaway and Eramosa were the earliest maturing, contained low specific gravities, high concentrations of glucose, and resulted into dark coloured chips. Specific gravities of the tubers were 1.079–1.088 in Atlantic, MS 700-70, MS 716-15 and W-855, 1.071–1.076 in Norchip, Kanona and Saginaw Gold and 1.056–1.068 in Eramosa and Onaway; harvest dates did not affect specific gravity.

De-Buchananne and Lawson (1991) studied the effect of plant population and harvest timing on potato yield and chipping quality at Muscatine and Whiting. They planted cultivars: Atlantic and Nor-Chip at in-row spacing of 15, 31, and 46 cm and harvested approximately 12, 14 and 16 week after planting. They obtained greater yield and greater specific gravity for both cultivars at final harvesting at both the locations. But chip colour was not significantly affected at Muscatine by harvest date while each successive date of harvest resulted in lighter coloured chips at Whiting. They further reported that higher plant population increased the yield but smaller increase in specific gravity was noted for both the cultivars. However, chip colour was not significantly influenced by the plant population. Cultivar 'Atlantic' produced lower yield having lower specific gravity as compared to ‘Nor-Chip’ throughout the season in the final harvest.

Simon and Richard (1989) conducted an experiment to find the effect of four dates of defoliation (0, + 10, + 20, + 30 days) and three days intervals to harvest (0, + 10, + 20 days) on yield, tuber size, dry matter, reducing sugar, fry test colour and finish fried sensory quality for two cultivars (Pentland Dell, Maris Piper) of potato. Dry matter content and yield of tuber were influenced by all factors in the trial. Later date of defoliation gave the lowest reducing sugar levels. Increasing the interval from defoliation to harvest reduced dry matter and raised yield.

Santerre *et al.* (1986) studied the influence of cultivars, harvest dates and soil nitrogen on sucrose, specific gravity and storage stability of potatoes grown in Michigan. They planted potato cultivars: Atlantic, Belchip, Denali, Monona, Nor-chip, and Russet Burbank and harvested them at weekly intervals from early August to early October. They obtained sucrose rating (mg sucrose/g of fresh tuber) below 1 by 145 days of growth. Higher nitrogen levels reduced the total yield for early harvests, but had no significant effect for later harvest. Changes in sucrose levels as tubers matured were helpful in evaluating the chemical maturity of more recently developed cultivars in relation to established chipping varieties.

Kundzicz (1985) stated that the influence of harvest date on the storage loss was considerable. The highest losses occurred at late harvest dates during the storage of cv. Sokol and Sowa. At early harvest dates the differences in the amount of damage were remarkable.

Peterson *et al.* (1981) observed that respiration rates of Potato tubers were high immediately after harvest, and declined to an equilibrium level after about 7 days. Weight loss during storage ranged from 8.3% to 3.7% in the early and late harvested samples.

Workman and Harrison (1980) studied the influence of harvest date on yield, early blight tuber infection and chipping characteristics of potatoes grown with sprinkler irrigation. Potato tuber yield was increased by late harvesting. Decreased tuber infection by *Alternaria solani* was attributed to maturation of the tuber periderm.

From the above review it is regarded that potato yield can be optimized with the judicial use of irrigation with optimum harvesting time during potato cultivation.

CHAPTER III

MATERIALS AND METHODS

This chapter presents a brief description about experimental period, site description, climatic condition, crop or planting materials, treatments, experimental design and layout, crop growing procedure, intercultural operations, data collection and statistical analysis. The details of experiments and methods are described below:

3.1 Experimental period

The experiment was conducted during the period from October 28, 2020 to March 20, 2021 in Rabi season.

3.2 Site description

3.2.1 Geographical location

The present piece of research work was conducted in the experimental plot of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is $23^0$74/N latitude and $90^0$35/E longitude with an elevation of 8.2 m from sea levels (Anon., 1988a).

3.2.2 Agro-Ecological Region

The experimental site belongs to the agro-ecological zone of “Modhupur Tract”, AEZ-28 (Anon., 1988a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hillocks of red soils as ‘islands’ surrounded by floodplain (Anon., 1988b). The experimental site was shown in the map of AEZ of Bangladesh in Appendix I.

3.2.3 Soil

Top soil was silty clay in texture, olive-gray with common fine to medium distinct dark yellowish-brown mottles. Soil pH was 5.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system and above flood levels. The selected plot was medium high land. The details were presented in Appendix II.

3.2.4 Climate of the experimental site

Experimental site was located in the sub-tropical monsoon climatic zone, set a parted by winter during the months from November, 10 to February, 15 (Rabi season). Plenty of sunshine and moderately low temperature prevails during experimental period, which is suitable for potato growing in Bangladesh. The weather data during the study period at the experimental site are shown in Appendix III.

3.3 Details of the Experiment

3.3.1 Experimental treatments

The experiment consisted of two factors such as irrigation frequency and harvesting time. The treatments were as follows:

Factor A: Irrigation frequency (3 levels)

1. I_1 – 3 Irrigation (at 15, 45 and 60 DAP),
2. I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and
3. I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

Factor B: Harvesting date (4 times)

1. H_1 – 85 DAP,
2. H_2 – 90 DAP,
3. H_3 - 95 DAP and
4. H_4 - 100 DAP.

12 treatment combinations were as:

1. I_1H_1 =3 Irrigation (at 15, 45 and 60 DAP)and85 DAP,
2. I_1H_2 =3 Irrigation (at 15, 45 and 60 DAP)and90 DAP,
3. I_1H_3 =3 Irrigation (at 15, 45 and 60 DAP)and95 DAP,
4. I_1H_4 =3 Irrigation (at 15, 45 and 60 DAP)and100 DAP,
5. I_2H_1=4 Irrigation (at 15, 30, 45 and 60 DAP) and85 DAP,
6. I_2H_2 =4 Irrigation (at 15, 30, 45 and 60 DAP) and90 DAP,
7. I_2H_3 =4 Irrigation (at 15, 30, 45 and 60 DAP) and95 DAP,
8. I_2H_4 =4 Irrigation (at 15, 30, 45 and 60 DAP) and100 DAP,
9. I_3H_1 =5 Irrigation (at 15, 30, 45, 60 and 75 DAP)and85 DAP,
10. I_3H_2 =5 Irrigation (at 15, 30, 45, 60 and 75 DAP)and90 DAP,
11. I_3H_3 = 5 Irrigation (at 15, 30, 45, 60 and 75 DAP)and95 DAPand
12. I_3H_4 =5 Irrigation (at 15, 30, 45, 60 and 75 DAP)and100 DAP.

3.3.2 Experimental design

The experiment was laid out in a split-plot design with three replications thus comprised 36 plots. Irrigation frequency was assigned to main plots and harvesting date to sub-plots. The layout of the experiment was prepared for distributing the combination of irrigation frequency and harvesting date. The size of each unit sub plot 2.50 m × 2.00 m. The spacing between blocks and plots were 1.00 m and 0.50 m, respectively.

3.4 Planting material

The planting materials comprised the first-generation tubers of BARI Alu-29(Courage).

3.5 Crop management

3.5.1 Collection of seed

The variety of seed potato (certified seed) was collected from, Tuber Crops Research Centre (TCRC), Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur.

3.5.2 Preparation of seed

Collected seed tubers were kept in room temperature to facilitate sprouting. Finally sprouted potato tubers were used as a planting material.

3.5.3 Land preparation

The land of the experimental site was first opened in the last week of October with power tiller. Later on, the land was ploughed and cross-ploughed four times followed by laddering to obtain the desirable tilth. The corners of the land were spaded and weeds and stubbles were removed from the field. The land was finally prepared on 4 November, 2020 three days before planting the seed. In order to avoid water logging due to rainfall during the study period, drainage channels were made around the land. The soil was treated with Furadan 5G @10 kg ha^{-1}when the plot was finally ploughed to protect the young plant from the attack of cut worm.

3.5.4 Fertilizer application

The crop was fertilized as per recommendation of TCRC (2004). The experimental plot was fertilized with following dose of muriate of potassium, triple super phosphate (TSP), gypsum, zinc sulphate and boric acid.

Fertilizer	Dose (kg ha^{-1})	Dose (g plot^{-1})
Cowdung	10,000	2000
Urea	300	70
MoP	300	70
TSP	220	52
Gypsum	120	27
Zinc Sulphate	14	5
Boric Acid	6	2

Source: Mondal *et al.*, 2011.

Cowdung was applied 10 days before final land preparation. Total amount of muriate of potassium, triple superphosphate, gypsum, zinc sulphate, boric acid was applied at basal doses during final land preparation. One third of urea was applied at final land preparation and one third was applied at 30 DAP. Finally rest amount was applied at 45 DAP.

3.5.5 Planting of seed tuber

The well sprouted healthy and uniform sized potato tubers were planted and 25 potatoes was used for one plot. Seed potatoes were planted in such a way that potato does not go much under soil or does not remain in shallow. On an average, potatoes were planted at 4-5 cm depth in plot on November 8, 2020.

3.5.6 Intercultural operations

3.5.6.1 Weeding and mulching

Weeding and mulching were necessary to keep the plots free from weeds, ease of aeration and conserve soil moisture. The newly emerged weeds were uprooted carefully after complete emergence of seedlings and afterwards when necessary. Mulching was done by breaking the surface crust as and when needed.

3.5.6.2 Irrigation

Irrigation frequency was done as per treatment.

3.5.6.3 Earthing up

Earthing up process was done by pouring the soil in the plot at two times, during crop growing period. First pouring was done at 35 DAP and second was at 50 DAP.

3.5.6.4 Plant protection measures

Sevin dust was used after sowing the seeds to prevent them from insect attack. Fungicide, Ridomil (0.25%) was sprayed at an interval of 10 days, commencing at 40 DAP as a preventive measure against late blight, Kenalux 0.1% was also sprayed in addition to Ridomil to protect the crop from the attack of virus disseminating aphid.

3.5.6.5 Haulm cutting

Haulm cutting was done when 40-50% plants showed senescence and the tops started drying. After haulm cutting the tubers were kept under the soil for 7 days for skin hardening. The cut haulm was collected, bagged and tagged separately for further data collection.

3.5.6.6 Harvesting of potatoes

Harvesting of potato was done at 7 days after haulm cutting as per treatment. The potatoes of each plot were separately harvested, bagged and tagged and brought to the laboratory. The yield of potato plant^{-1} was determined in gram. Harvesting was done manually by hand.

3.5.7 Recording of data

Experimental data were recorded from 20 days after planting (DAP) and continued until harvest. Dry weights of different plant parts were collected after harvesting. The following data were collected during the experimentation.

A. Crop growth characters

i. Days to 1st emergence and days to 90% emergence,

ii. Plant height (cm) at 30, 50 and 70 DAP,

iii. Number of stems plant^{-1} at 30, 50 and 70 DAP,

iv. Number of leaves plant^{-1} at 30, 50 and 70 DAP,

B. Yield and yield components

v. Number of tubers hill^{-1},

vi. Average tuber weight (g),

vii. Weight of tuber hill^{-1} (g),

viii. Yield of tuber (t ha^{-1}),

ix. Yield of marketable tuber (t ha^{-1}),

x. Yield of non-marketable tuber (t ha^{-1}),

C. Quality characters

xi. Dry matter content (%),

xii. Specific gravity (g cm^{-3}),

xiii. Total soluble solids (°Brix),

xiv. Reducing suger (mg g^{-1} FW),

xv. Starch content (mg g^{-1} FW) and

xvi. Yield of potato for different processing purpose (t ha^{-1}).

3.5.8 Experimental measurements

A brief outline of the data recording procedure followed during the study is given below:

A. Crop growth characters

i. Days to 1st emergence and days to 90% emergence

After planting the potato tuber keenly observed the emergence twice in a day (morning and afternoon) until 90% emergence.

ii. Plant height (cm)

Plant height refers to the length of the plant from ground levels to the tip of the tallest stem. It was measured at an interval of 20 days starting from 30 DAP till 70 DAP. The height of each plant of each plot was measured in cm with the help of a meter scale and mean was calculated.

iii. Number of stems $plant^{-1}$

Number of stems $plant^{-1}$ was counted at an interval of 20 days starting from 30 DAP till 70 DAP. Stem numbers $plant^{-1}$ was recorded by counting all stem from each plot.

iv. Number of leaves plant^{-1}

Number of leaves plant^{-1} was counted at an interval of 20 days starting from 30 DAP till 70 DAP. Leaves number plant^{-1} were recorded by counting all leaves from each plant of each plot and mean was calculated.

B. Yield and yield components

v. Number of tubershill^{-1}

Number of tubers hill^{-1} was counted at harvest. Tuber numbers hill^{-1}was recorded by counting all tubers from each plant.

vi. Average tuber weight (g)

Average tuber weight was measured by using the following formula-

$$\text{Average tuber weight (g)} = \frac{\text{Yield of tuber plot}^{-1}}{\text{Number of tubers plot}^{-1}}$$

vii. Weight of tuber hill^{-1} (g)

Tubers of each plot were collected separately from which weight of tuber hill^{-1} was recorded in gram.

viii. Yield of tuber (t ha^{-1})

Tubers of each plot were collected separately from which yield of tuber hill-1 was recorded in kilogram and converted to ton ha-1.

ix. Yield of marketable tuber and non-marketable tuber (t ha^{-1})

On the basis of weight, the tubers have been graded into marketable tuber (>20g) and non-marketable tuber (< 20 g) and converted to percentages (Hussain, 1995).

C. Quality characters

x. Dry matter content (%)

The samples of tuber were collected from each treatment. After peel off the tubers the samples were dried in an oven at 72^0C for 72 hours. Dry matter content was calculated as the ratio between dry and fresh weight and expressed as a percentage (Barton and Longman, 1989).

xi. Specific Gravity (g cm^{-3})

It was measured by using the following formula (Gould, 1995)-

$$\text{Specific gravity (g cm}^{-3}\text{)} = \frac{\text{Weight of tuber in air}}{\text{Weight of tuber in water at } 4^0 \text{ C}}$$

xii. Total soluble solids (TSS) (°brix)

TSS of harvested tubers was determined in a drop of potato juice by using Hand Sugar Refractometer "ERMA" Japan, Range: 0-32%according to (AOAC, 1990)and expressed as BRIX value.

xiii. Reducing sugar (mg g^{-1} FW)

xiii. i. Extraction of sugar

For the analysis of sugar content like glucose and sucrose potato flesh was extracted. For each extraction, 1.0g fresh sample of chopped potato was taken from uniform tuber samples. Sugar was extracted using 5ml of 80% ethanol heat at 80°C for 30 min using a dry block heat bath and the extracts was centrifuged at 5000 rpm for 10 min and decanted the supernatant. 8mL 80% EtOH, was added and it was repeated 4 and 5 for 3 times in total. All the supernatants were mixed well and the final volume was made up to 25 mL using 80% EtOH.The residue is used for starch analysis.

xiii. ii. Reducing sugar determination (glucose)

Reducing sugar was estimated by the photometric adaptation of the Somogyi method with some modification. Copper solution and Nelson reagent and standard glucose solution (0.5 mL) were used. 3 mL sample solution was put into a small glass container. Then it was completely dried up on an electric heater, 3 mL distilled water was added, and then mixed well. Then .5ml solution was taken from this, two times and was put in different test tubes. In one test tube, 0.5 mL Copper solution was added and was boiled (100°C) for 10 min. After boiling, immediately the test tube was cooled in tap water. 0.5 mL Nelson reagent in the test tube was added, and mixed them well. After 20 min, 8 mL distilled water was added and mixed well (Total volume = 9.5 mL). 33 After that the absorbance at 660 nm (Abs1) was measured and the reducing sugar content was calculated.

xiv. Determination of starch content (mg g^{-1} FW)

Starch content of tubers was determined by Somogyi-Nelson method (Nelson, 1944). Preparation of phosphate buffer. Dilute 0.74 $NaH_2PO_4.2H_2O$ and 0.09g $NaH_2PO_4.12H_2O$ into 100 ml Distilled water. Add 0.10 g Enzyme (Amylo glucosidase) and mix well. Keep at - 20°C for the preservation. Measure 250 ml tap water using a measuring cylinder and put it into a 250 ml beaker. Take 0.50 ml solution from the beaker into 3 test tubes. Boil the test tubes for 10 min at 100°C. Add 1.00 ml Amylo glucosidase solution, mix well and heat at 50 - 60°C for 2 hoursin hot water. After cooling, add 0.50 ml Copper solution, mix well heat at 100°C for 10 minutes, cool in tap water, add 0.50 ml Nelson solution, mix well, add 7 ml distilled water, mix well (Final volume = 9.50 ml), and measure the absorbance at 660 nm (Abs). Calculate starch content using the glucose standard curve.

Calculation of starch content-

$$\text{Starch} = \text{Abs} \times 0.9$$

xv. Grading of tuber (t ha^{-1})

Tubers harvested from each treatment were graded by weight on the basis of diameter into the <30 mm (Canned potato), 30-45 mm (Dehydrated potato), 45-75 mm (Chips potato) and >75 mm (French fries' potato) and converted to g plant^{-1} and percentages (Hussain, 1995). A special type of frame (potato riddle) was used to grading of tuber.

3.6 Statistical Analysis

The data obtained for different characters were statistically analyzed following the analysis of variance techniques by using MSTAT-C computer package programme. The significant differences among the treatment means were compared by Least Significant Different (LSD) at 5% levels of probability (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The experiment was conducted to find out the effect of irrigation frequency and dates of harvesting on yield and quality of export and processing potatoes. The results obtained from the study have been presented, discussed and compared in this chapter through table(s) and figures. The analysis of variance of data in respect of all the parameters has been shown in Appendix IV to XI. The results have been presented and discussed with the help of table and graphs and possible interpretations given under the following headings.

4.1 Days to 1st emergence (Visual observation)

4.1.1 Effect of irrigation frequency

Days to 1st emergence was insignificantly influenced by the irrigation frequency (Appendix IV and Figure1). Numerically, the I_1 (3 Irrigation at 15, 45 and 60 DAP) and I_3 (5 Irrigation at 15, 30, 45, 60 and 75 DAP) treatment took the maximum (11.67 days) for 1st emergence whereas, the minimum (11.42 days) was taken by I_2 (4 Irrigation at 15, 30, 45 and 60 DAP) treatment. Emergence depends on soil moisture, soil temperature, seed temperature, disease and physiological age of seed. Fertilizer affects the plant when plant had root. Roots are being developed 10-15 days after emergence.

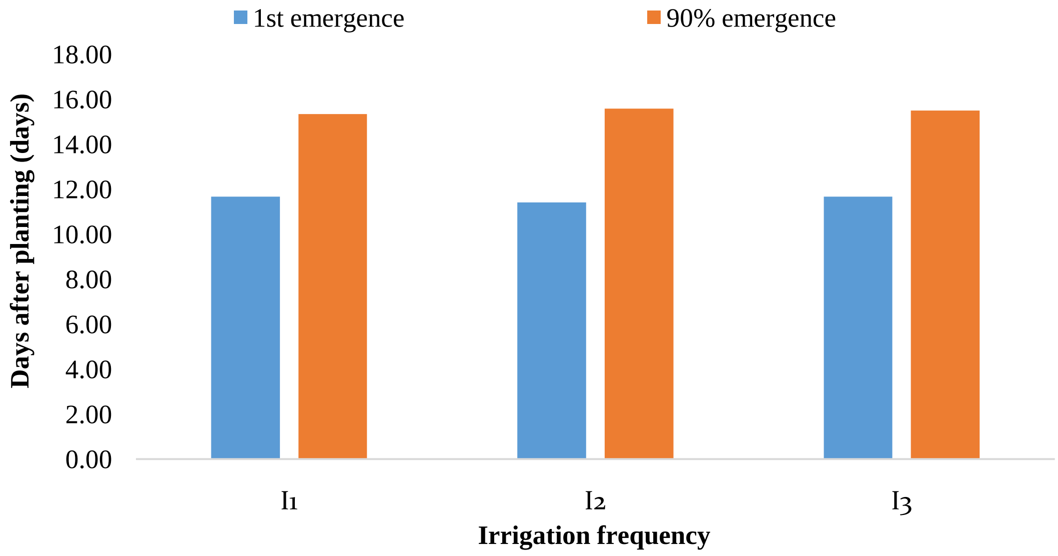

Figure 1. Effect of irrigation frequency on days to first and 90% emergence (days) of potato (LSD value = Non-significant and Non-significant, respectively)

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

4.1.2 Interaction effect of irrigation frequency and harvesting date

Interaction effect of irrigation frequency and harvesting date insignificantly influenced by days to 1st emergence of potato (Appendix IV and Table 1). Numerically, the maximum duration for 1st emergence (12.00 days) was recorded from the combination of '3 Irrigation at 15, 45 and 60 DAP with harvesting at 100 DAP' (I_1H_4) treatment whereas, the minimum duration (11.33 days) was recorded from the combination of I_1H_3 (3 Irrigation at 15, 45 and 60 DAP with harvesting at 95 DAP), I_2H_1 (4 Irrigation at 15, 30, 45 and 60 DAP with harvesting at 85 DAP), I_2H_2 (4 Irrigation at 15, 30, 45 and 60 DAP with harvesting at 90 DAP) and I_2H_4 (4 Irrigation at 15, 30, 45 and 60 DAP with harvesting at 100 DAP) treatment.

Table 1. Interaction effects of irrigation frequency and harvesting date on days to first and 90% emergence (days) of potato

Treatment combination	Days to first emergence (days)	Days to 90% emergence (days)
I_1H_1	11.67	15.00
I_1H_2	11.67	15.67
I_1H_3	11.33	15.33
I_1H_4	12.00	15.33
I_2H_1	11.33	15.33
I_2H_2	11.33	15.67
I_2H_3	11.67	15.67
I_2H_4	11.33	15.67
I_3H_1	11.67	15.67
I_3H_2	11.67	15.00
I_3H_3	11.67	15.33
I_3H_4	11.67	16.00
$LSD_{(0.05)}$	**---**	**---**
CV (%)	**4.78**	**7.32**
Level of significance	**NS**	**NS**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP. NS- Non-significant

4.2 Days to 90% emergence (Visual observation)

4.2.1 Effect of irrigation frequency

Days to 90% emergence was insignificantly influenced by the irrigation frequency, results revealed that, then duration of emergence increased gradually with increasing the rate of irrigation (Appendix IV and Figure 1). Numerically, the minimum to 90% emergence (15.33 days) was required in I_1 (3 Irrigation at 15, 45 and 60 DAP) treatment and the maximum (15.58 days) was recorded in I_3 (5 Irrigation at 15, 30, 45, 60 and 75 DAP). This result showed that 15, 45 and 60 DAP (3 irrigation) was the early emergence.

4.2.2 Interaction effect of irrigation frequency and harvesting date

Interaction effect of irrigation frequency and harvesting date insignificantly influenced the days taken to 90% emergence of potato (Appendix IV and Table 1). Numerically, the minimum duration for 90% emergence (15.00 days) was recorded from the combination of I_1H_1 (3 Irrigation at 15, 45 and 60 DAP and harvesting at 85 DAP) and I_3H_2 (5 Irrigation at 15, 30, 45, 60 and 75 DAP with harvesting at 90 DAP) treatment. On the other hand, the numerically maximum duration (16.00 days) was recorded from the combination of '5 Irrigation at 15, 30, 45, 60 and 75 DAP with harvesting at 100 DAP' (I_3H_4) treatment.

4.3 Plant height

4.3.1 Effect of irrigation frequency

Plant height was significantly influenced by irrigation frequency at 3 growth stages (30, 50 and 70 DAP) of potato (Figure 2 and Appendix V). Result showed that plant height increased with increasing irrigation frequency (Figure 2). The tallest plant was recorded in 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) (51.59, 63.07 and 73.22 cm at 30, 50 and 70 DAP, respectively) at all growth stages. In contrast, the 3 irrigation (at 15, 45 and 60 DAP) had the shortest plant height at all growth stages (45.88, 58.28 and 66.59 cm at 30, 50 and 70 DAP, respectively) while was statistically similar to I_2 (4 irrigation at 15, 30, 45 and 60 DAP) (59.81 and 68.63 cm at 50 and 70 DAP, respectively). The plant height was the tallest in maximum irrigation because of seedling had huge stored food material that supported increased vegetative growth of the plants. Akkamis and Caliskan (2021) stated that the vegetative growth phase of potato plant begins with the sprouting of the seed piece and extends to stolon formation.

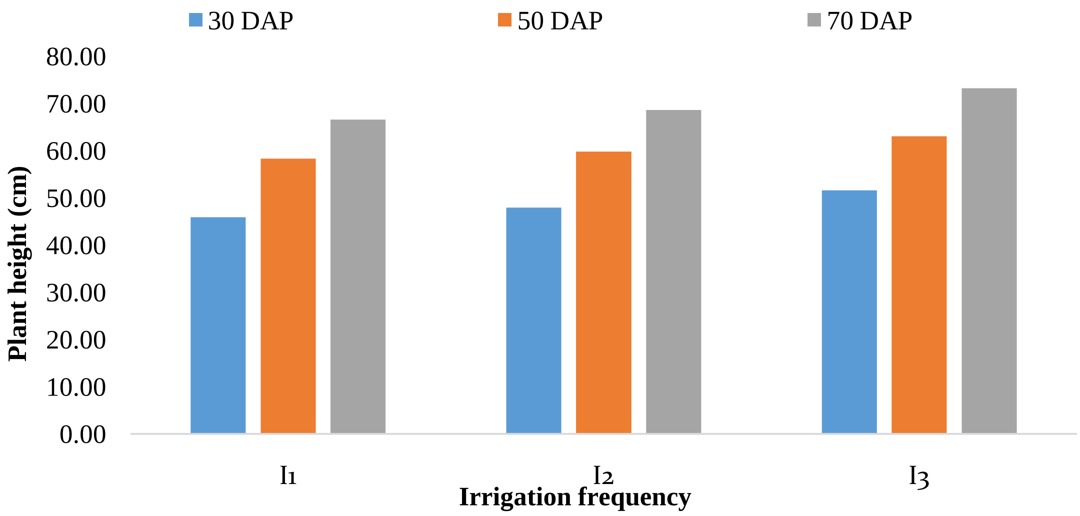

Figure 2. Effect of irrigation frequency on plant height (cm) of potato at different days after planting (LSD value = 2.05, 2.68 and 3.51 at 30, 50 and 70 DAP, respectively)

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

4.3.2 Interaction effect of irrigation frequency and harvesting date

The interaction effect of irrigation frequency and harvesting time had significant effect on plant height at three growth stages of 30, 50 and 70 DAP in potato (Appendix V and Table 2). At 30 DAP, the tallest plant was recorded in the treatment combination of 5 Irrigation with 100 DAP harvesting time (52.80 cm) which was statistically similar to I_3H_2 (52.00 cm) and I_3H_1 (51.02 cm) treatment combination whereas, the lowest was recorded in the treatment combination of 3 Irrigation with 95 DAP harvest (44.47 cm) which was statistically similar to I_1H_1 (45.53 cm)treatment combination. At 50 DAP, the tallest plant was recorded in the treatment combination of 5 Irrigation with 100 DAP harvesting time (64.83 cm) which was statistically similar to I_3H_2 (64.00 cm) treatment combination whereas, the lowest was recorded in the treatment combination of 3 Irrigation with 95 DAP harvest (56.63 cm) which was statistically similar to I_1H_4 (57.90 cm), I_1H_1 (59.00 cm) and I_2H_3 (59.00 cm)treatment combination. At 70 DAP, the tallest plant was recorded in the treatment combination of 5 Irrigation with 100 DAP harvesting time (75.03 cm) which was statistically similar to I_3H_2 (74.37 cm) and I_3H_3 (72.57 cm) treatment combination whereas, the lowest was recorded in the treatment combination of 3 Irrigation with 95 DAP harvest (62.97 cm).

Table 2. Interaction effects of irrigation frequency and harvesting date on plant height (cm) of potato at different days after planting

Treatment combination	Plant height (cm) at		
	30 DAP	**50 DAP**	**70 DAP**
I_1H_1	45.53 ef	59.00 d-f	66.30 e
I_1H_2	46.80 c-e	59.59 c-e	70.00 b-d
I_1H_3	44.47 f	56.63 f	62.97 f
I_1H_4	46.73 de	57.90 ef	67.10 de
I_2H_1	47.10 c-e	59.33 de	68.37 de
I_2H_2	48.67 b-d	61.40 cd	70.33 bc
I_2H_3	47.37 c-e	59.00 d-f	66.90 e
I_2H_4	48.70 bc	59.50 de	68.90 c-e
I_3H_1	51.02 ab	61.43 cd	70.90 bc
I_3H_2	52.00 ab	64.00 ab	74.37 a
I_3H_3	50.53 b	62.00 bc	72.57 ab
I_3H_4	52.80 a	64.83 a	75.03 a
LSD $_{(0.05)}$	**1.95**	**2.45**	**3.06**
CV (%)	**3.87**	**5.47**	**5.81**
Level of significance	**0.01**	**0.01**	**0.01**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP.

4.4 Number of stems $plant^{-1}$

4.4.1 Effect of irrigation frequency

Irrigation frequency exerted significant effect on stems $plant^{-1}$ in potato at 30, 50 and 70 DAP (Appendix VI and Figure 3). Result revealed that number of stems $plant^{-1}$ increased with increasing irrigation frequency. The maximum number of stems $plant^{-1}$ was observed in the 5 Irrigation at 15, 30, 45, 60 and 75 (4.92, 5.50 and 5.92 at 30, 50 and 70 DAP, respectively) followed by 4 Irrigation at 15, 30, 45 and 60 DAP (3.92, 4.33 and 4.92 at 30, 50 and 70 DAP, respectively). In contrast, the minimum number of stems $plant^{-1}$ was recorded in the 3 Irrigation at 15, 45 and 60 DAP (3.08, 3.75 and 4.25 at 30, 50 and 70 DAP, respectively). The increase of stem $plant^{-1}$ obtained from the maximum irrigation might be due to the higher number of potential eyes present per tuber which led to production of higher stems $plant^{-1}$.

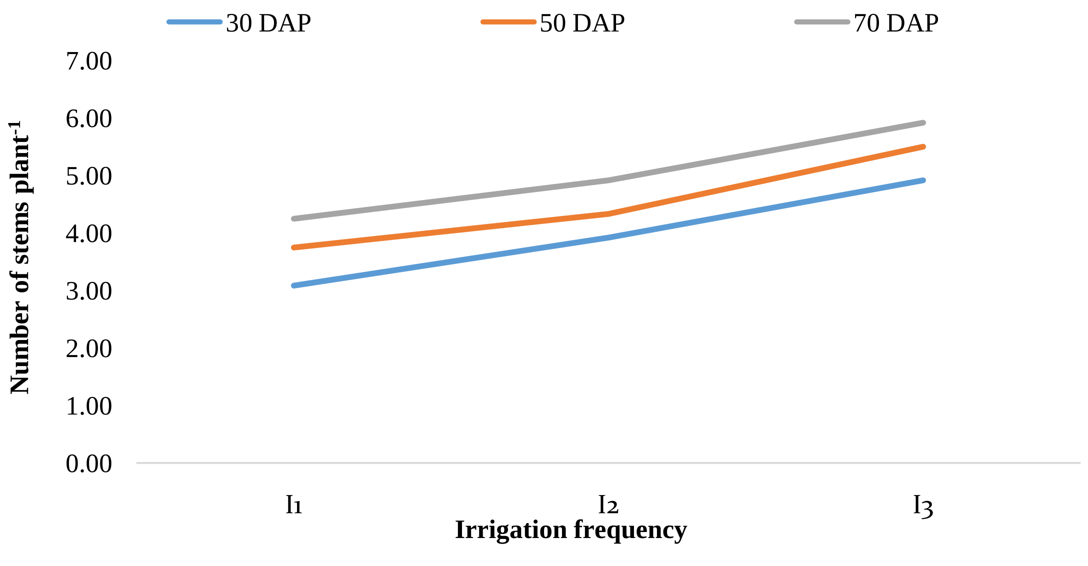

Figure 3. Effect of irrigation frequency on number of stems $plant^{-1}$ of potato at different days after planting (LSD value = 0.19, 0.31 and 0.39 at 30, 50 and 70 DAP, respectively)

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

4.4.2 Interaction effect of irrigation frequency and harvesting date

The interaction effect between irrigation frequency and harvesting time had significant effect on stems plant^{-1} (Appendix VI and table 3). The highest stems plant^{-1} (5.67, 6.67 and 7.00 at 30, 50 and 70 DAP, respectively) was observed in treatment combination of 5 Irrigation at 15, 30, 45, 60 and 75 DAP with harvesting at 100 DAP. On the other hand, the lowest stems plant^{-1} (2.33, 2.67 and 3.00 at 30, 50 and 70 DAP, respectively) was recorded in the treatment combination of 3 Irrigation at 15, 45 and 60 DAP with harvesting at 85 DAP.

Table 3. Interaction effects of irrigation frequency and harvesting date on number of stems plant^{-1} of potato at different days after planting

Treatment combination	Number of stems plant^{-1} at		
	30 DAP	**50 DAP**	**70 DAP**
I_1H_1	2.33 i	2.67 j	3.00 k
I_1H_2	3.00 h	3.67 h	4.00 j
I_1H_3	3.33 g	4.00 g	4.33 i
I_1H_4	3.67 f	4.67 e	5.67 d
I_2H_1	3.00 h	3.00 i	3.67 h
I_2H_2	3.67 f	4.33 f	5.00 f
I_2H_3	4.33 d	4.67 e	5.00 f
I_2H_4	4.67 c	5.33 c	6.00 c
I_3H_1	4.00 e	4.33 f	4.67 g
I_3H_2	4.67 c	5.00 d	5.33 e
I_3H_3	5.33 b	6.00 b	6.67 b
I_3H_4	5.67 a	6.67 a	7.00 a
$LSD_{(0.05)}$	**0.11**	**0.24**	**0.28**
CV (%)	**7.24**	**5.16**	**7.91**
Level of significance	**0.05**	**0.05**	**0.05**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP.

4.5 Number of leaves plant^{-1}

4.5.1 Effect of irrigation frequency

The effect of irrigation frequency on number of leaves plant^{-1} was statistically significant at 3 growth stages (Appendix VII and Figure 4). The highest leaf number was observed in 3 Irrigation frequency (33.17, 49.08 and 53.02 plant^{-1} at 30, 50 and 70 DAP, respectively) and the lowest leaf number was recorded in 5 Irrigation frequency (27.92, 41.50 and 44.67 plant^{-1} at 30, 50 and 70 DAP, respectively). Increased leaf number in lowest irrigation frequency be due to decreased stems plant^{-1}.

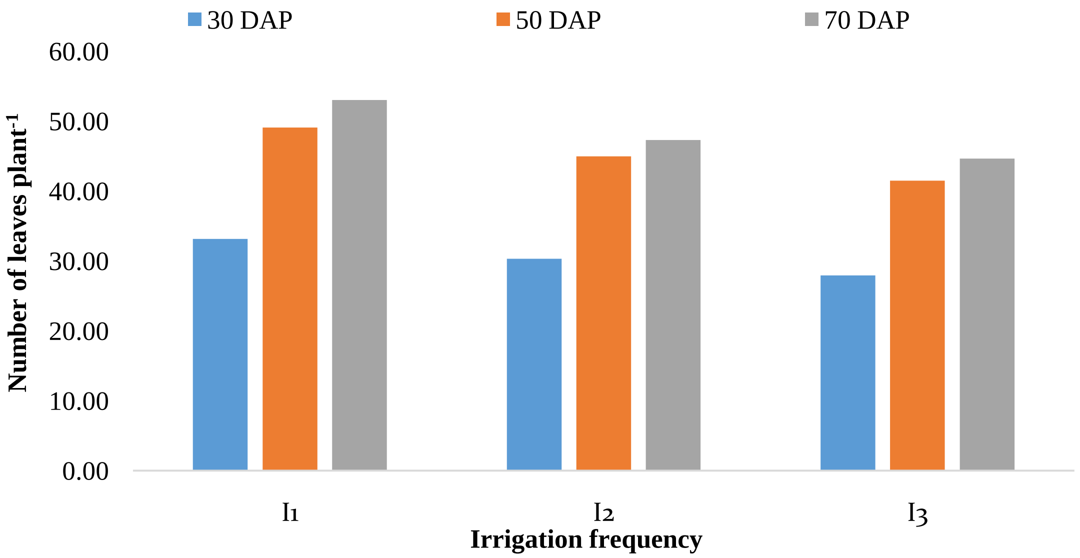

Figure 4. Effect of irrigation frequency on number of leaves plant^{-1} of potato at different days after planting (LSD value = 2.81, 3.49 and 2.37 at 30, 50 and 70 DAP, respectively)

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

4.5.2 Interaction effect of irrigation frequency and harvesting date

The interaction effect of irrigation frequency and harvesting time had significant effect on number of leaves plant^{-1} (Appendix VII and Table 4). The highest leaf number (41.67, 56.00 and 50.37 plant^{-1} at 30, 50 and 70 DAP, respectively) was observed in the treatment combination 3 irrigation frequency with 85 DAP harvest (I_1H_1). On the other hand, the lowest leaf number (19.00, 32.00 and 35.67 plant^{-1} at 30, 50 and 70 DAP, respectively) was recorded in the treatment combination of 5 Irrigation frequency with 100 DAP harvest (I_3H_4) which was statistically identical to I_2H_4 (35.00 plant^{-1} at 50 DAP) treatment combination.

Table 4. Interaction effects of irrigation frequency and harvesting date on number of leaves plant^{-1} of potato at different days after planting

Treatment combination	**Number of leaves plant^{-1} at**		
	30 DAP	**50 DAP**	**70 DAP**
I_1H_1	41.67 a	56.00 a	60.37 a
I_1H_2	35.67 bc	50.33 bc	54.67 b
I_1H_3	31.00 d	47.33 cd	49.70 cd
I_1H_4	24.33 ef	42.67 ef	47.33 e
I_2H_1	36.33 b	52.33 b	54.00 b
I_2H_2	33.67 c	49.33 bc	51.00 c
I_2H_3	29.00 d	43.33 ef	46.00 ef
I_2H_4	22.33 f	35.00 g	38.33 g
I_3H_1	37.67 b	48.00 cd	51.00 c
I_3H_2	30.00 d	45.00 de	48.00 de
I_3H_3	25.00 e	41.00 f	44.00 f
I_3H_4	19.00 g	32.00 g	35.67 h
LSD $_{(0.05)}$	**2.51**	**3.35**	**2.05**
CV (%)	**8.04**	**3.86**	**5.67**
Level of significance	**0.05**	**0.05**	**0.05**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP.

4.6 Number of tubers hill^{-1}

4.6.1 Effect of irrigation frequency

Number of tubers hill^{-1} significantly influenced by the irrigation frequency (Appendix VIII and Table 5). The maximum number of tubers hill^{-1} (11.65) was recorded from 5 Irrigation at 15, 30, 45, 60 and 75 DAP (I_3) treatment which was statistically similar to I_2 (11.39) treatment. On the other hand, the minimum number of tubers hill^{-1} (10.51) was found from the 3 Irrigation at 15, 45 and 60 DAP (I_3) treatment.

Table 5. Effects of irrigation frequency on number of tubers hill^{-1}, average tuber weight and weight of tuber hill^{-1} of potato

Treatment	No. of tubers hill^{-1}	Average tuber weight (g)	Weight of tuber hill^{-1} (g)
I_1	10.51 b	30.14 c	316.77 c
I_2	11.39 ab	31.88 b	363.11 b
I_3	11.65 a	33.94 a	395.40 a
LSD $_{(0.05)}$	**1.04**	**0.93**	**12.59**
CV (%)	**4.06**	**6.39**	**5.78**
Level of significance	**0.05**	**0.05**	**0.05**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

4.6.2 Effect of harvesting date

Number of tubers hill^{-1}non-significantly influenced by different harvesting date (Appendix VIII and Table 6). Numerically, the maximum number of tubers hill^{-1} (11.53) was produced from the '95 DAP' harvest (H_3) followed by H_4 (11.52) and H_2 (11.03) treatment and the minimum (10.64) was produced from the '85 DAP' harvest (H_1) treatment. Present study showed that tuber numbers increased within '95 DAP' harvest then decreased and increased the size of tuber. Thus, the increased sized tuber influenced on total yield of tuber.

Table 6. Effects of harvesting date on number of tubers hill^{-1}, average tuber weight and weight of tuber hill^{-1} of potato

Treatment	No. of tubers hill^{-1}	Average tuber weight (g)	Weight of tuber hill^{-1} (g)
H_1	10.64	29.98 d	318.99 d
H_2	11.03	31.21 c	344.25 c
H_3	11.53	32.88 b	379.11 b
H_4	11.52	33.88 a	390.30 a
LSD $_{(0.05)}$	**---**	**0.78**	**8.62**
CV (%)	**4.06**	**6.39**	**5.78**
Level of significance	**NS**	**0.01**	**0.01**

Note: H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP. NS- Non-significant

4.6.3 Interaction effect of irrigation frequency and harvesting date

Interaction effect of different irrigation frequency and harvesting time showed significant variation in respect of number of tubers hill^{-1} (Appendix VIII and Table 7). The maximum number of tubers hill^{-1} (12.23) was recorded from the combination of '5 Irrigation frequency at 15, 30, 45, 60 and 75 DAP with 100 DAP harvest' (I_3H_4) treatment which was statistically at par to I_3H_3 (12.22), I_2H_4 (11.67), I_2H_2 (11.43), I_2H_3 (11.33) and I_3H_2 (11.33) treatment. On the other hand, the minimum number of tubers hill^{-1} (10.00) was recorded from the combination of '3 Irrigation at 15, 45 and 60 DAP with 85 DAP harvest' (I_1H_1) treatment which was statistically similar to I_1H_2 (10.33) and I_1H_4 (10.67) treatment.

Table 7. Interaction effects of irrigation frequency and harvesting date on number of tubers hill^{-1}, average tuber weight and weight of tuber hill^{-1} of potato

Treatment combination	No. of tubers hill^{-1}	Average tuber weight (g)	Weight of tuber hill^{-1} (g)
I_1H_1	10.00 e	27.57 i	275.70 h
I_1H_2	10.33 de	28.68 h	296.26 g
I_1H_3	11.02 b-d	31.76 ef	350.00 e
I_1H_4	10.67 c-e	32.54 de	347.20 e
I_2H_1	11.12 b-d	29.96 g	333.16 f
I_2H_2	11.43 a-c	31.27 f	357.42 e
I_2H_3	11.33 a-c	32.77 cd	371.28 d
I_2H_4	11.67 ab	33.50 bc	390.95 c
I_3H_1	10.80 b	32.40 de	349.92 e
I_3H_2	11.33 a-c	33.67 b	381.48 c
I_3H_3	12.22 a	34.11 b	416.82 b
I_3H_4	12.23 a	35.60 a	435.38 a
LSD $_{(0.05)}$	**0.95**	**0.78**	**8.62**
CV (%)	**4.06**	**6.39**	**5.78**
Level of significance	**0.05**	**0.05**	**0.01**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP.

4.7 Average tuber weight

4.7.1 Effect of irrigation frequency

Average tuber weight significantly varied among the different irrigation frequency of potato (Appendix VIII and Table 5). The maximum tuber weight (33.94 g) was observed from I_3 (5 irrigation) while the minimum (30.14 g) was observed from I_1 (3 irrigation) treatment.

4.7.2 Effect of harvesting date

Average tuber weight was significantly differed by different harvesting date of potato (Appendix VIII and Table 6). Results revealed that the maximum tuberweight (33.88 g) was achieved from H_4 (100 DAP harvest) treatmentwhereas, the minimum (29.98 g) was found in H_1 (85 DAP harvest) treatment. The result obtained from thepresent study was similar with Yourtchi *et al*. (2013).

4.7.3 Interaction effect of irrigation frequency and harvesting date

Treatment combination of irrigation frequency and harvesting times influenced the average tuber weight significantly (Appendix VIII and Table 7). The average tuber weight was observed the maximum in '5 Irrigation frequency' with harvested at 100 DAP (35.60 g) while the minimum (27.57 g) was found on '3 Irrigation frequency' with harvested at 85 DAP.

4.8 Weight of tuber hill^{-1}

4.8.1 Effect of irrigation frequency

It was observed from the results that different irrigation frequency significantly varied with the tuber weight hill^{-1} (Appendix VIII and Table 5). The maximum (395.40 g) was found in 5 irrigation at 15, 30, 45, 60 and 75 DAP (I_3) treatment, while the minimum (316.77 g) was recorded from 3 irrigation at 15, 45 and 60 DAP (I_1) treatment. Present study reviled that modern irrigation system '5 Irrigation frequency' produced maximum tuber weight hill^{-1}.

4.8.2 Effect of harvesting date

Weight of tubers hill^{-1} varied significantly with different harvesting dates (Appendix VIII and Table 6). The maximum tuber weight hill^{-1} (390.30 g) recorded from the harvest at 100 DAP (H_4) treatment, while the minimum (318.99 g) was in 85 DAP harvest (H_1) treatment. Present study showed that tuber weight of all variety increased with maturity time. Increasing maturity time helps to gather more plant dry bio-mass which leads to increase weight of tubers. Khan *et al.* (2011) also found that tuber yield increased with the delay in harvesting.

4.8.3 Interaction effect of irrigation frequency and harvesting date

Treatment combination of irrigation frequency and harvesting times influenced the weight of tubers hill^{-1} significantly (Appendix VIII and Table 7). The weight of tubers hill^{-1} was observed the maximum (435.38 g) in 5 irrigation at 15, 30, 45, 60 and 75 DAP with harvested at 100 DAP (I_3H_4) treatment combination, while the minimum (275.70 g) was found on 3 irrigation at 15, 45 and 60 DAP with harvested at 85 DAP (I_1H_1) treatment combination. From this study it was showed that tuber weight of all variety increased with maturity time. Increasing maturity time helps to gather more plant dry bio-mass which leads to increase weight of tubers. Khan *et al.* (2011) also found that tuber yield increased with the delay in harvesting.

4.9 Yield of tuber

4.9.1 Effect of irrigation frequency

Significant variation was found among irrigation frequency to tuber yield (Appendix IX and Figure 5). The highest (32.94 t ha^{-1}) yield of tuber was found from I_3 (5 Irrigation frequency) treatment whereas, the lowest (26.23 t ha^{-1}) was found from I_1 (3 Irrigation frequency) treatment.

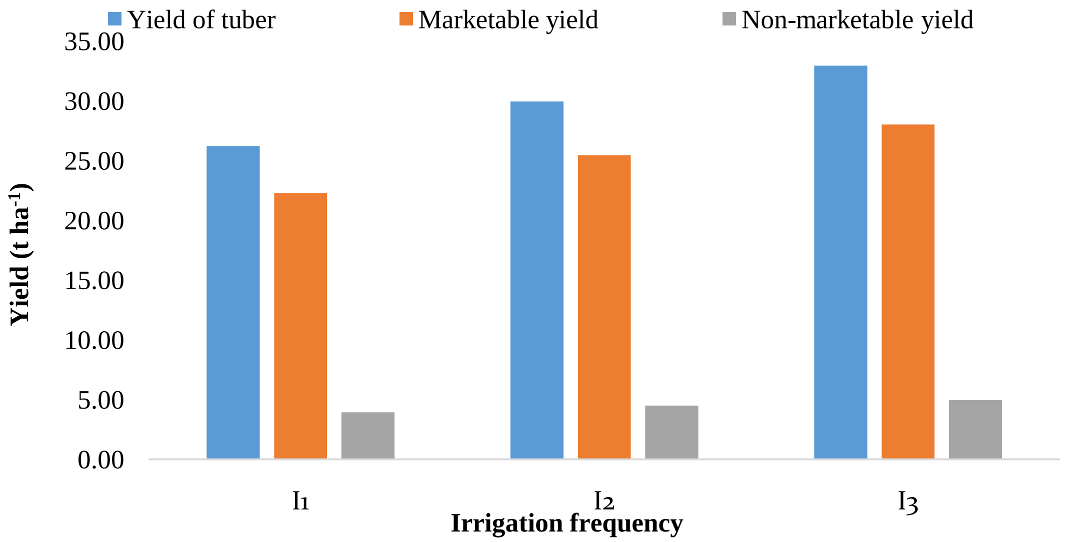

Figure 5. Effect of irrigation frequency on yield of tuber (t ha^{-1}), yield of marketable tuber (t ha^{-1}) and yield of non-marketable tuber (t ha^{-1}) of potato (LSD value = 1.45, 0.86 and 0.43, respectively)

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP).

4.9.2 Effect of harvesting date

Significant variation in respect of tuber yield was observed on the different harvesting time (Appendix IX and Figure 6). The highest (32.59 t ha^{-1}) tuber yield was recorded in harvesting at 100 DAP which was statistically identical (31.42 t ha^{-1}) to harvesting at 95 DAP whereas, the lowest (26.32 t ha^{-1}) was recorded from 85 DAP. Harvesting at 95 and 100 DAP showed statistically similar yield. The maximum increase in yield was noticed between 85 and 95 DAP. Again, lower tuber yield per plant as well as per unit area under lower days of harvesting time was might be due to lesser amount of assimilate produced by the plants through lesser photosynthetic time plant-1 and nutrients uptake by the plants. Khan *et al.* (2011) found that total number of tubers, tuber yield and plant dry biomass increased with the delay in harvesting.

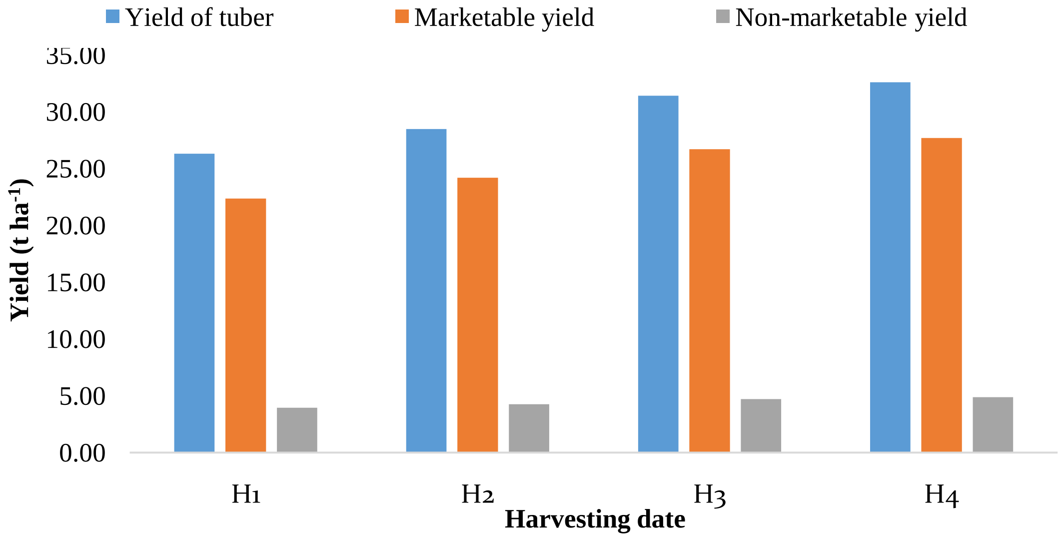

Figure 6. Effect of harvesting date on yield of tuber (t ha^{-1}), yield of marketable tuber (t ha^{-1}) and yield of non-marketable tuber (t ha^{-1}) of potato (LSD value = 1.88, 0.71 and 0.31, respectively)

Note: H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP.

4.9.3 Interaction effect of irrigation frequency and harvesting date

Treatment combination of irrigation frequency and different harvesting time had also significant effect on tuber yield (Appendix IX and Table 8). Among the twenty treatment combinations, the 5-irrigation frequency with harvested at 100 DAP attained the highest tuber yield (36.31 t ha^{-1}) which was statistically identical with I_3H_3 (34.46 t ha^{-1}) treatment combination whereas, the lowest yield (22.57 t ha^{-1}) was recorded in 3 Irrigation frequency with harvested at 85 DAP treatment combination which was statistically similar with I_1H_2 (24.31 t ha^{-1}) treatment combination.

4.10 Yield of marketable tuber

4.10.1 Effect of irrigation frequency

Marketable yield (t ha^{-1}) was significantly influenced by different irrigation frequency of potato cultivation (Appendix IX and Figure 5). The maximum marketable yield of tuber (28.00 t ha^{-1}) was found from I_3 (5 irrigation at 15, 30, 45, 60 and 75 DAP) treatment whereas, the minimum (22.29 t ha^{-1}) was found from I_1 (3 irrigation 15, 45 and 60 DAP) treatment. This variation might be due to different tuber size of potato.

4.10.2 Effect of harvesting date

Different harvesting date significantly influenced on marketable yield of potato tuber (Appendix IX and Figure 6). Harvesting at 100 DAP gave the maximum marketable yield of potato tuber (27.70 t ha^{-1}) while the minimum (22.37 t ha^{-1}) was obtained from harvesting at 85 DAP. Present study showed that maximum marketable yield of potato tuber increased with maturity time up to certain time. Again, lower tuber yield per hectare under lower days of harvesting time was might be due to lesser amount of assimilate produced by the plants through lesser photosynthetic time plant-1 and nutrients uptake by the plants. This result is consistent with many workers in potato (Yenagi *et al*., 2005; Kushwah and Singh, 2008). Khan *et al.* (2011) found that total number of tubers increased with the delay in harvesting.

4.10.3 Interaction effect of irrigation frequency and harvesting date

Combined effect of different irrigation frequency and harvesting date showed statistically significant variation in marketable yield of potato tuber (Appendix IX and Table 8). The maximum marketable yield of potato tuber (30.86 t ha^{-1}) was recorded from 5 Irrigation and harvested at 100 DAP while, the minimum (19.19 t ha^{-1}) was recorded from 3 Irrigation and harvested at 85 DAP. Present study showed that tuber numbers of potato increased with maturity time up to certain time. Khan *et al.* (2011) also found that total number of tubers increased with the delay in harvesting.

4.11 Yield of non-marketable tuber

4.11.1 Effect of irrigation frequency

Significant variation was found among different irrigation frequency to non-marketable yield (Appendix IX and Figure 5). The highest (4.94 t ha^{-1}) non-marketable yield of tuber was found from I_3 (5 irrigation at 15, 30, 45, 60 and 75 DAP) treatment whereas, the lowest (3.93 t ha^{-1}) was found from I_1 (3 irrigation 15, 45 and 60 DAP) treatment. This variation might be due to different tuber size and percentage of tuber size of potato.

4.11.2 Effect of harvesting date

Different harvesting time significantly influenced on non-marketable yield of potato tuber (Appendix IX and Figure 6). Harvesting at 100 DAP gave the highest non-marketable yield of potato tuber (4.89 t ha^{-1}) which was statistically identical to harvesting at 95 DAP (4.71 t ha^{-1}), while the lowest (3.95 t ha^{-1}) was obtained from harvesting at 85 DAP.

4.11.3 Interaction effect of irrigation frequency and harvesting date

Combined effect of different irrigation frequency and harvesting time showed statistically significant variation in non-marketable yield of potato tuber (Appendix IX and table 8). The highest non-marketable yield of potato tuber (5.45 t ha^{-1}) was recorded from % irrigation frequency with harvested at 100 DAP which was statistically identical with I_3H_3 (5.17 t ha^{-1}) treatment combination, while the lowest (3.39 t ha^{-1}) was recorded from 3 irrigation frequency with harvested at 85 DAP which was statistically identical with I_1H_2 (3.65 t ha^{-1}) treatment combination.

Table 8. Interaction effects of irrigation frequency and harvesting date on the yield of potato

Treatment combination	Tuber yield (t ha^{-1})	Marketable yield (t ha^{-1})	Non-marketable yield (t ha^{-1})
I_1H_1	22.57 e	19.19 h	3.39 e
I_1H_2	24.31 e	20.66 g	3.65 e
I_1H_3	28.98 cd	24.63 e	4.35 cd
I_1H_4	29.05 cd	24.69 e	4.36 cd
I_2H_1	27.20 d	23.12 f	4.08 d
I_2H_2	29.31 c	24.92 e	4.40 c
I_2H_3	30.81 bc	26.18 d	4.62 bc
I_2H_4	32.42 b	27.55 c	4.86 b
I_3H_1	29.19 c	24.81 e	4.38 cd
I_3H_2	31.81 b	27.04 c	4.77 b
I_3H_3	34.46 a	29.29 b	5.17 ab
I_3H_4	36.31 a	30.86 a	5.45 a
LSD $_{(0.05)}$	**1.88**	**0.71**	**0.31**
CV (%)	**9.07**	**5.49**	**7.05**
Level of significance	**0.05**	**0.05**	**0.05**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP.

4.12 Yield of potato for different processing purpose

4.12.1 Yield of potato for canned production (20-35 mm)

4.12.1.1 Effect of irrigation frequency

The effect of irrigation frequency on the yield of potato for canned production was statistically significant at 3 growth stages (Appendix XI and Table 9). The highest canned production was observed in 5 Irrigation frequency (8.24 t ha^{-1}) and the lowest value was recorded in 3 Irrigation frequency (6.56 t ha^{-1}).

4.12.1.2 Effect of harvesting date

The yield of potato for canned production showed significant differences among harvesting time (Appendix XI and Table 10). The highest canned production (8.15 t ha^{-1}) was recorded for harvesting time 100 DAP whereas, the lowest value (6.58 t ha^{-1}) was recorded for harvesting time 85 DAP.

4.12.1.3 Interaction effect of irrigation frequency and harvesting date

The interaction effect of irrigation frequency and harvesting date had significant effect on the yield of potato for canned production (Appendix XI and Table 11). The highest canned production (9.08 t ha^{-1}) was observed in the combination of 5 irrigation frequency with 100 DAP harvest (I_3H_4) treatment. On the other hand, the lowest canned production (5.64 t ha^{-1}) was recorded in the combination of 3 Irrigation frequency with 85 DAP harvest (I_1H_1) treatment.

Table 9. Effects of irrigation frequency on the yield of potato for different processing purpose

Treatment	Yield of potato for canned production (t ha^{-1}) (20-35 mm)	Yield of potato for flakes production (t ha^{-1}) (35-45 mm)	Yield of potato for chip production (t ha^{-1}) (45-75 mm)	Yield of potato for French fry production (t ha^{-1}) (> 75 mm)
I_1	6.56 c	11.80 c	7.87 c	NF
I_2	7.48 b	13.47 b	8.98 b	NF
I_3	8.24 a	14.83 a	9.88 a	NF
LSD $_{(0.05)}$	**0.24**	**0.47**	**0.34**	**---**
CV (%)	**6.27**	**4.12**	**6.31**	**---**
Level of significance	**0.01**	**0.05**	**0.01**	**NS**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP). NS- Non-significant

4.12.2 Yield of potato for flakes production (35-45 mm)

4.12.2.1 Effect of irrigation frequency

The yields of potato for flakes production was significantly influenced by the different Irrigation frequency (Appendix XI and table 9). The highest flakes production (14.83 t ha^{-1}) was obtained from I_3 (5 Irrigation at 15, 30, 45, 60 and 75 DAP) treatment and the lowest ones (11.80 t ha^{-1}) was obtained from I_1 (3 Irrigation at 15, 45 and 60 DAP) treatment.

4.12.2.2 Effect of harvesting date

The yields of potato for flakes production was significantly affected by the different harvesting date (Appendix XI and Table 10). The highest flakes production (14.67 t ha^{-1}) was obtained from H_4 (100 DAP harvest) treatment and the lowest ones (11.84 t ha^{-1}) was obtained from H_1 (85 DAP harvest) treatment.

4.12.2.3 Interaction effect of irrigation frequency and harvesting date

The yields of potato for flakes production due to different irrigation frequency and harvesting date was found statistically significant (Appendix XI and Table 11). The highest (16.34 t ha^{-1}) flakes production exhibited by I_3H_4 (5 irrigation frequency with 100 DAP harvest) treatment combination whereas, the lowest ones (10.16 t ha^{-1}) was exhibited by I_1H_1 (3 Irrigation frequency with 85 DAP harvest) treatment combination.

Table 10. Effects of harvesting date on the yield of potato for different processing purpose

Treatment	Yield of potato for canned production (t ha^{-1}) (20-35 mm)	Yield of potato for flakes production (t ha^{-1}) (35-45 mm)	Yield of potato for chip production (t ha^{-1}) (45-75 mm)	Yield of potato for French fry production (t ha^{-1}) (> 75 mm)
H_1	6.58 d	11.84 d	7.90 d	NF
H_2	7.12 c	12.82 c	8.54 c	NF
H_3	7.85 b	14.14 b	9.42 b	NF
H_4	8.15 a	14.67 a	9.78 a	NF
$LSD_{(0.05)}$	**0.17**	**0.31**	**0.27**	**---**
CV (%)	**6.27**	**4.12**	**6.31**	**---**
Level of significance	**0.05**	**0.05**	**0.01**	**NS**

Note: H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP. NS- Non-significant

4.12.3 Yield of potato for chip production (45-75 mm)

4.12.3.1 Effect of irrigation frequency

The yields of potato for chips production was significantly affected by the different irrigation frequency (Appendix XI and Table 9). The maximum chips production (9.88 t ha^{-1}) was obtained from I_3 (5 Irrigation at 15, 30, 45, 60 and 75 DAP) treatment, while the minimum ones (7.87 t ha^{-1}) was obtained from I_1 (3 Irrigation at 15, 45 and 60 DAP) treatment.

4.12.3.2 Effect of harvesting date

The yields of potato for chips production was significantly affected by the different harvesting date (Appendix XI and Table 10). The maximum chips production (9.78 t ha^{-1}) was obtained from H_4 (100 DAP harvest) treatment whereas, the minimum chips production (7.90 t ha^{-1}) was obtained from H_1 (85 DAP harvest) treatment.

4.12.3.3 Interaction effect of irrigation frequency and harvesting date

The yields of potato for chips production due to different irrigation frequency and harvesting date was found statistically significant (Appendix XI and table 11). The maximum (10.89 t ha^{-1}) chips production exhibited by I_3H_4 (5 irrigation frequency with 100 DAP harvest) treatment combination. On the other hand, the minimum (6.77 t ha^{-1}) chips production was exhibited by I_1H_1 (3 Irrigation frequency with 85 DAP harvest) treatment combination.

4.13 Specific gravity

4.13.1 Effect of irrigation frequency

No significant variation in respect of specific gravity was observed for the different irrigation frequency (Appendix X and Table 12). 5 Irrigation at 15, 30, 45, 60 and 75DAP (I_3) treatment showed numerically, the highest specific gravity (1.064 g cm^{-3}) whereas, the lowest value (1.043 g cm^{-3}) was recorded in 4 Irrigation at 15, 30, 45 and 60 DAP (I_2) treatment.

4.13.2 Effect of harvesting date

Specific gravity was insignificantly affected by different harvesting date (Appendix X and Table 13). The specific gravity of tubers significantly increased with increasing harvesting time. The numerically highest specific gravity of tuber (1.058 g cm^{-3}) was recorded from 100 DAP which whereas, the lowest value (1.047 g cm^{-3}) was recorded from 85 DAP. Jeong*et al.* (1996) reported gradual increase in specific gravity until 100 days after planting, and showed a decrease thereafter, present study also showed that specific gravity gradually increased with increasing harvesting time up to 100 DAP, and showed a decrease thereafter. Marwaha (1998) also observed an increase in the specific gravity of tubers with the increase in harvesting time.

Table 11. Interaction effects of irrigation frequency and harvesting date on the yield of potato for different processing purpose

Treatment combination	Yield of potato for canned production (t ha^{-1}) (20-35 mm)	Yield of potato for flakes production (t ha^{-1}) (35-45 mm)	Yield of potato for chip production (t ha^{-1}) (45-75 mm)	Yield of potato for French fry production (t ha^{-1}) (> 75 mm)
I_1H_1	5.64 h	10.16 h	6.77 h	NF
I_1H_2	6.08 g	10.94 g	7.29 g	NF
I_1H_3	7.24 e	13.04 e	8.69 e	NF
I_1H_4	7.26 e	13.07 e	8.71 e	NF
I_2H_1	6.80 f	12.24 f	8.16 f	NF
I_2H_2	7.33 e	13.19 e	8.79 e	NF
I_2H_3	7.70 d	13.86 d	9.24 d	NF
I_2H_4	8.10 c	14.59 c	9.73 c	NF
I_3H_1	7.30 e	13.14 e	8.76 e	NF
I_3H_2	7.95 c	14.32 c	9.54 c	NF
I_3H_3	8.62 b	15.51 b	10.34 b	NF
I_3H_4	9.08 a	16.34 a	10.89 a	NF
LSD $_{(0.05)}$	**0.17**	**0.31**	**0.27**	**---**
CV (%)	**6.27**	**4.12**	**6.31**	**---**
Level of significance	**0.05**	**0.05**	**0.05**	**NS**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – 85 DAP, H_2 – 90 DAP, H_3 - 95 DAP and H_4 - 100 DAP. NS- Non-significant

4.13.3 Interaction effect of irrigation frequency and harvesting date

Combined effect of irrigation frequency and different harvesting time significantly influenced on specific gravity of potato tubers (Appendix X and Table 14). Among the 12 treatment combinations, '5 Irrigation frequency' exhibited the highest (1.070 g cm^{-3}) specific gravity at 100 DAP, while '4 Irrigation frequency' showed the lowest specific gravity (1.041 g cm^{-3}) at 85 DAP. Tubers that have a longer time to accumulate carbohydrates will generally have higher specific gravity than those with shorter growth periods. This result agreed with (Misra *et al.*, 1993; Marwaha, 1998; Ali *et al.*, 2003;

Elfnesh *et al.*, 2011; Mehta *et al.*, 2011), who reported that specific gravity and DM content increased with the maturity of tuber and crops grown usually have more time to mature those produce tubers with high specific gravity and DM content. A positive correlation between specific gravity and dry matter of tubers was observed earlier (Walter *et al.*, 1997).

4.14 Dry matter content

4.14.1 Effect of irrigation frequency

Tuber Dry Matter (DM) content was significantly affected by different irrigation frequency of potato field (Appendix X and Table 12). Among three types of irrigation frequency, '5 Irrigation' showed the maximum (22.18 %) DM content, while '3 Irrigation' was recorded minimum (20.67 %) DM content. The rate of accumulation of dry matter depended on cultivar, which was confirmed in the study by Gąsiorowska and Zarzecka (2002). According to Rytel (2004) and Lisińska (2006), delayed harvest results in increased dry matter contents of potato but the rate of their accumulation depends on cultivar and growing conditions.

Table 12. Effects of irrigation frequency on the processing qualities of potato

Treatment	Specific gravity (g cm^{-3})	Dry matter content (%)	Total soluble solid (*brix)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
I_1	1.051	20.67 c	5.47 a	14.28 c	0.443 a
I_2	1.043	21.19 b	5.38 a	16.38 b	0.398 b
I_3	1.064	22.18 a	5.16 b	17.45 a	0.295 c
$LSD_{(0.05)}$	**---**	**0.57**	**0.12**	**0.63**	**0.05**
CV (%)	**9.64**	**3.81**	**6.46**	**5.02**	**6.01**
Level of significance	**NS**	**0.01**	**0.01**	**0.01**	**0.01**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP). NS- Non-significant

4.14.2 Effect of harvesting date

Tuber dry matter content was significantly affected by different harvesting time (Appendix X and Table 13). The maximum dry matter content of tuber (22.17 %) was recorded from harvested at 100 DAP whereas, the minimum (20.72 %) was recorded from harvested at 85 DAP. The results of this study demonstrated that the time to harvest affected dry matter content of tubers. These results are consistent with those of Muli and Agili (2010), whose study demonstrated that the percent dry matter increased as more time was allowed for tuber development, before harvesting. According to Rytel (2004) and Lisińska (2006), delayed harvest results in increased starch and dry matter contents of potato.

4.14.3 Interaction effect of irrigation frequency and harvesting date

Combined effect of irrigation frequency and different harvesting time significantly influenced on dry matter content of potato tubers (Appendix X and Table 14). Among the 12 treatment combinations, '5 Irrigation' tubers exhibited the maximum (22.67 %) DM content at 100 DAP which was statistically similar with I_3H_3 (22.42 %) and I_2H_4 (22.27 %) treatment combination, while '3 Irrigation' showed the minimum (20.00 %) DM content at 85 DAP which was statistically similar with I_1H_2 (20.33 %) treatment combination. Tubers that have a longer time to accumulate carbohydrates will generally have higher DM content than those with shorter growth periods. This result is in agreement with (Misra *et al.*, 1993; Marwaha, 1998; Ali *et al.*, 2003; Elfnesh *et al.*, 2011; Mehta *et al.*, 2011) who reported that DM content increased with the maturity of tuber and crops grown usually have more time to mature those produce tubers with high DM content. A positive correlation between specific gravity and dry matter of tubers was observed earlier (Walter *et al.*, 1997).

Table 13. Effects of harvesting date on the processing qualities of potato

Treatment	Specific gravity (g cm^{-3})	Dry matter content (%)	Total soluble solid (*brix)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
H_1	1.047	20.72 c	5.56 a	15.80	0.470 a
H_2	1.052	21.16 b	5.43 b	15.97	0.407 b
H_3	1.054	21.34 b	5.25 c	16.10	0.350 c
H_4	1.058	22.17 a	5.12 d	16.27	0.287 d
LSD $_{(0.05)}$	**---**	**0.41**	**0.08**	**---**	**0.03**
CV (%)	**9.64**	**3.81**	**6.46**	**5.02**	**6.01**
Level of significance	**NS**	**0.01**	**0.01**	**NS**	**0.01**

Note: H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP. NS- Non-significant

4.15 Total soluble solids

4.15.1 Effect of irrigation frequency

Irrigation frequency differed significantly between themselves regarding TSS (Appendix X and Table 12). The maximum TSS (5.47 %) was recorded from 3 Irrigation 15, 45 and 60 DAP (I_1) treatment which was statistically identical to I_2 (5.38 %) treatment whereas; the minimum TSS (5.16 %) was obtained from the control treatment. Study referred that the higher irrigation expressed lower result in terms of TSS.

4.15.2 Effect of harvesting date

Different harvesting time had significant effect on TSS of potato (Appendix X and Table 13). The maximum TSS (5.56 %) was found from the ‘85 DAP’ harvest and the minimum TSS (5.12 %) was found from the ’100 DAP’ harvest.

4.15.3 Interaction effect of irrigation frequency and harvesting date

It was found that TSS was affected significantly due to the interaction of irrigation frequency and harvesting date (Appendix X and Table 14). The highest TSS (5.73 %) was recorded from the combination of 3 Irrigation with '85 DAP' harvest (I_1H_1) treatment whereas, the minimum value (4.93 %) was found from 5 Irrigation with '100 DAP' harvest (I_3H_4) treatment.

4.16 Starch content

4.16.1 Effect of irrigation frequency

Significant variation was found on starch content on potato due to different irrigation frequency (Appendix X and table 12). The highest starch content on potato (17.45 mg g^{-1} FW) was attained by I_3 (5 irrigation at 15, 30, 45, 60 and 75 DAP). On the other hand, the lowest starch content on potato (14.28 mg g^{-1} FW) was attained by I_1 (3 irrigation at 15, 45 and 60 DAP).

4.16.2 Effect of harvesting date

No significant variation was found among different harvesting date on starch content of tuber (Appendix X and table 13). Numerically, the highest (16.27 mg g^{-1} FW) starch content of tuber was contained by H_4 (100 DAP harvest). On the other hand, numerically, the lowest (15.80 mg g^{-1} FW) starch content of tuber was contained by H_1 (85 DAP harvest).

4.16.3 Interaction effect of irrigation frequency and harvesting date

Significant variation was found on starch content on potato due to interaction effect of different irrigation frequency and harvesting date (Appendix X and Table 14). The highest starch content on potato (17.70 mg g^{-1} FW) was attained by I_3H_4 (5 irrigation at 15, 30, 45, 60 and 75 DAP with 100 DAP harvest) treatment combination which was statistically similar with I_3H_3 (17.50 mg g^{-1} FW) andI_3H_2 (17.40 mg g^{-1} FW). On the other hand, the lowest starch content on potato (14.10 mg g^{-1} FW) was attained by I_1H_1 (3 irrigation at 15, 45 and 60 DAP with 85 DAP harvest) treatment combination which was statistically identical with I_1H_2 (14.20 mg g^{-1} FW),I_1H_3 (14.30 mg g^{-1} FW) and I_1H_4 (14.50 mg g^{-1} FW).

Table 14. Interaction effects of irrigation frequency and harvesting date on the processing qualities of potato

Treatment combination	Specific gravity (g cm^{-3})	Dry matter content (%)	Total soluble solid (*brix)	Starch content (mg g^{-1} FW)	Reducing sugar (mg g^{-1} FW)
I_1H_1	1.045	20.00 g	5.73 a	14.10 e	0.510 a
I_1H_2	1.047	20.33 fg	5.63 b	14.20 e	0.490 a
I_1H_3	1.052	20.50 f	5.33 e	14.30 e	0.420 b
I_1H_4	1.060	21.84 cd	5.18 f	14.50 e	0.350 de
I_2H_1	1.041	20.67 f	5.52 c	16.10 d	0.490 a
I_2H_2	1.043	21.00 ef	5.43 d	16.30 cd	0.410 bc
I_2H_3	1.044	21.10 e	5.32 e	16.50 cd	0.380 cd
I_2H_4	1.045	22.27 ab	5.25 ef	16.60 c	0.310 e
I_3H_1	1.054	21.50 de	5.42 d	17.20 b	0.410 bc
I_3H_2	1.064	22.00 bc	5.21 f	17.40 ab	0.320 e
I_3H_3	1.067	22.42 ab	5.09 g	17.50 ab	0.250 f
I_3H_4	1.070	22.67 a	4.93 h	17.70 a	0.200 g
$LSD_{(0.05)}$	**---**	**0.41**	**0.08**	**0.49**	**0.03**
CV (%)	**9.64**	**3.81**	**6.46**	**5.02**	**6.01**
Level of significance	**NS**	**0.01**	**0.01**	**0.01**	**0.01**

Note: I_1 – 3 Irrigation (at 15, 45 and 60 DAP), I_2 – 4 Irrigation (at 15, 30, 45 and 60 DAP) and I_3 - 5 Irrigation (at 15, 30, 45, 60 and 75 DAP) and H_1 – harvesting at 85 DAP, H_2 – harvesting at 90 DAP, H_3 - harvesting at 95 DAP and H_4 - harvesting at 100 DAP. NS- Non-significant

4.17 Reducing sugar

4.17.1 Effect of irrigation frequency

Reducing sugar has significantly influenced different irrigation frequency of potato cultivation (Appendix X and Table 12). The maximum reducing sugar value (0.443 mg g^{-1} FW) was recorded from the "3 Irrigation" (I_1) whereas, the minimum value (0.295 mg g^{-1} FW) was found from the "5 Irrigation" (I_3). Reducing sugar content increase with the increasing irrigation frequency.

4.17.2 Effect of harvesting date

Reducing sugar has significantly influenced different harvesting date (Appendix X and Table 13). The maximum reducing sugar value (0.470 mg g^{-1} FW) was recorded from the "85 DAP harvest" (H_1) whereas, the minimum value (0.287 mg g^{-1} FW) was found from the "100 DAP harvest" (H_4) treatment. Reducing sugar content decrease with the increasing harvest times.

4.17.3 Interaction effect of irrigation frequency and harvesting date

Interaction effect of irrigation frequency and harvesting date had significant effect of reducing sugar content of potato (Appendix X and table 14). The maximum reducing sugar content (0.510 mg g^{-1} FW) was recorded in I_1H_1 (3 Irrigation with 85 DAP harvest) which was statistically identical with I_1H_2 (0.490 mg g^{-1} FW) and I_2H_1(0.490 mg g^{-1} FW) treatment combination whereas, the minimum value of potato (0.200 mg g^{-1} FW) was observed in I_3H_4 (5 Irrigation with 100 DAP harvest) treatment combination.

CHAPTER V

SUMMARY AND CONCLUSION

The field experiment was conducted at Sher-e-Bangla Agricultural University during the period from October, 2020 to March, 2021 in Rabi season to find out the effect of irrigation frequency and harvesting date on yield and quality of export and processing potato. The experiment had two factors. Factor A: Irrigation frequency: 3 levels; I_1: 3 irrigation at 15, 45 and 60 DAP, I_2: 4 irrigation at 15, 30, 45 and 60 DAP, I_3: 5 irrigation at 15, 30, 45, 60 and 75 DAP and Factor B: harvesting date: 4 times; H_1: harvesting at 85 DAP, H_2: harvesting at 90 DAP, H_3: harvesting at 95 DAP and H_4: harvesting at 100 DAP. The experiment was laid out in a split-plot design with three (3) replications. Total 36 unit plots were made for the experiment with 12 treatments. Irrigation frequency was assigned to main plots and harvesting date to sub-plots. Each pot was of required size. The variety was BARI Alu-29 (Courage).Data on different growth parameter, yield and qualitative parameter of potato were recorded and significant variation was recorded for different treatment.

In case of irrigation frequency, the 3 irrigation and 5 irrigation took the maximum days (11.67 days) for 1st emergence whereas, the minimum (11.42 days) was taken by 4 irrigation. The maximum (15.58 days) was recorded in I_3 treatment and the minimum days to 90% emergence (15.33 days) was required in I_1 treatment. The tallest plant was recorded in 5 Irrigation (51.59, 63.07 and 73.22 cm at 30, 50 and 70 DAP, respectively) at all growth stages whereas, the 3 irrigation had the shortest plant (45.88, 58.28 and 66.59 cm at 30, 50 and 70 DAP, respectively). The maximum number of stems plant^{-1} was observed in the 5 Irrigation (4.92, 5.50 and 5.92 at 30, 50 and 70 DAP, respectively), while the minimum value was recorded in the 3 Irrigation (3.08, 3.75 and 4.25 at 30, 50 and 70 DAP, respectively). The highest leaf number was observed in 3 Irrigation frequency (33.17, 49.08 and 53.02 plant^{-1} at 30, 50 and 70 DAP, respectively) and the lowest leaf number was recorded in 5 Irrigation frequency (27.92, 41.50 and 44.67 plant^{-1} at 30, 50 and 70 DAP, respectively). The maximum number of tubers hill^{-1} (11.65) was recorded in I_3 treatment and the minimum number of tubers hill^{-1} (10.51) was found from I_3 treatment. The height tuber weight (33.94 g) was observed from I_3 (5 irrigation) while the lowest tuber weight (30.14 g) was observed from I_1 (3 irrigation) treatment. The maximum tuber weight hill^{-1} (395.40 g) was found in I_3 treatment, while the minimum (316.77 g) was recorded from I_1 treatment. The highest (32.94 t ha^{-1}) yield of tuber was found from I_3 (5 Irrigation frequency) treatment whereas, the lowest (26.23 t ha^{-1}) was found from I_1 (3 Irrigation frequency) treatment. The maximum (28.00 t ha^{-1}) marketable yield of tuber was found from I_3 treatment whereas, the minimum (22.29 t ha^{-1}) was found from I_1 treatment. The highest (4.94 t ha^{-1}) non-marketable yield of tuber was found from I_3 (5 irrigation at 15, 30, 45, 60 and 75 DAP) treatment whereas, the lowest (3.93 t ha^{-1}) was found from I_1 (3 irrigation 15, 45 and 60 DAP) treatment. 5 Irrigation at 15, 30, 45, 60 and 75DAP treatment showed the numerically highest specific gravity (1.064 g cm^{-3}) whereas, the lowest value (1.043 g cm^{-3}) was recorded in 4 Irrigation at 15, 30, 45 and 60 DAP (I_2) treatment.Among three types of irrigation frequency, '5 Irrigation' showed the maximum (22.18 %) DM content, while '3 Irrigation' was recorded minimum (20.67 %) DM content. The maximum TSS (5.47 %) was recorded from 3 Irrigation 15, 45 and 60 DAP (I_1) treatment which was statistically identical to I_2 (5.38 %) treatment whereas; the minimum TSS (5.16 %) was obtained from the control treatment. The highest starch content on potato (17.45 mg g^{-1} FW) was attained by I_3 treatment and the lowest ones (14.28 mg g^{-1} FW) was attained by I_1 treatment. The maximum reducing sugar value (0.443 mg g^{-1} FW) was recorded from the "3 Irrigation" (I_1) whereas, the minimum value (0.295 mg g^{-1} FW) was found from the "5 Irrigation" (I_3). The highest canned production was observed in 5 Irrigation frequency (8.24 t ha^{-1}) and the lowest value was recorded in 3 Irrigation frequency (6.56 t ha^{-1}). The highest flakes production (14.83 t ha^{-1}) was obtained from I_3 treatment and the lowest ones

(11.80 t ha^{-1}) was obtained from I_1 treatment. The maximum chips production (9.88 t ha^{-1}) was obtained from I_3 treatment, while the minimum ones (7.87 t ha^{-1}) was obtained from I_1 treatment.

In case of harvesting date, the maximum number of tubers $hill^{-1}$ (11.53) was produced from the '95 DAP' harvest (H_3) treatment and the minimum (10.64) was produced from the '85 DAP' harvest (H_1) treatment. Results revealed that the height tuberweight (33.88 g) was achieved from H_4 treatmentwhereas, the lowest value (29.98 g) was found in H_1 treatment. The maximum tuber weight $hill^{-1}$ (390.30 g) recorded from the harvest at 100 DAP (H_4) treatment, while the minimum (318.99 g) was in 85 DAP harvest (H_1) treatment. The highest (32.59 t ha^{-1}) tuber yield was recorded in harvesting at 100 DAP whereas, the lowest (26.32 t ha^{-1}) was recorded from 85 DAP. Harvesting at 100 DAP gave the maximum marketable yield of potato tuber (27.70 t ha^{-1}) while the minimum (22.37 t ha^{-1}) was obtained from harvesting at 85 DAP. Harvesting at 100 DAP gave the highest non-marketable yield of potato tuber (4.89 t ha^{-1}), while the lowest (3.95 t ha^{-1}) was obtained from harvesting at 85 DAP. The highest specific gravity of tuber (1.058 g cm^{-3}) was recorded from 100 DAP whereas, the lowest value (1.047 g cm^{-3}) was recorded from 85 DAP. The maximum dry matter content of tuber (22.17 %) was recorded from harvested at 100 DAP, while the minimum (20.72 %) was recorded from harvested at 85 DAP. The maximum TSS (5.56 %) was found from the '85 DAP' harvest and the minimum TSS (5.12 %) was found from the '100 DAP' harvest. The highest (16.27 mg g^{-1} FW) starch content of tuber was contained by H_4 (100 DAP harvest) and the lowest (15.80 mg g^{-1} FW) starch content of tuber was contained by H_1 (85 DAP harvest). The maximum reducing sugar value (0.470 mg g^{-1} FW) was recorded from the "85 DAP harvest" (H_1) whereas, the minimum value (0.287 mg g^{-1} FW) was found from the "100 DAP harvest" (H_4) treatment. The highest canned production (8.15 t ha^{-1}) was recorded for harvesting time 100 DAP whereas, the lowest value (6.58 t ha^{-1}) was recorded for harvesting time 85 DAP. The highest flakes production (14.67 t ha^{-1}) was obtained from H_4 treatment and the lowest ones (11.84 t ha^{-1}) was obtained from H_1 treatment. The maximum chips production (9.78 t ha^{-1}) was obtained from H_4 treatment whereas, the minimum chips production (7.90 t ha^{-1}) was obtained from H_1 treatment.

In the case of interaction effects of irrigation frequency and harvesting date, the maximum duration for 1st emergence (12.00 days) was recorded from the combination of I_1H_4 (3 Irrigation at 15, 45 and 60 DAP with harvesting at 100 DAP) treatment whereas, the minimum duration (11.33 days) was recorded from the combination of I_1H_3 (3 Irrigation at 15, 45 and 60 DAP with harvesting at 95 DAP), I_2H_1 (4 Irrigation at 15, 30, 45 and 60 DAP with harvesting at 85 DAP), I_2H_2 (4 Irrigation at 15, 30, 45 and 60 DAP with harvesting at 90 DAP) and I_2H_4 (4 Irrigation at 15, 30, 45 and 60 DAP with harvesting at 100 DAP) treatment. The minimum duration for 90% emergence (15.00 days) was recorded from the combination of I_1H_1 and I_3H_2 treatment whereas, the maximum duration (16.00 days) was recorded from the combination of I_3H_4 treatment. At 70 DAP, the tallest plant was recorded in the treatment combination of 5 Irrigation with 100 DAP harvesting time (75.03 cm) whereas, the lowest was recorded in the treatment combination of 3 Irrigation with 95 DAP harvest (62.97 cm).At 30, 50 and 70 DAP, the highest stems $plant^{-1}$ (5.67, 6.67 and 7.00, respectively) was observed in treatment combination of 5 Irrigation at 15, 30, 45, 60 and 75 DAP with 100 DAP harvest and the lowest (2.33, 2.67 and 3.00, respectively) was recorded in the treatment combination of 3 Irrigation at 15, 45 and 60 DAP with 85 DAP harvest. At 30, 50 and 70 DAP, the highest leaf number (41.67, 56.00 and 50.37 $plant^{-1}$, respectively) was observed in the treatment combination of I_1H_1, while the lowest value (19.00, 32.00 and 35.67 $plant^{-1}$, respectively) was recorded in the treatment combination of I_3H_4. The maximum number of tubers $hill^{-1}$ (12.23) was recorded from the combination of '5 Irrigation frequency at15, 30, 45, 60 and 75 DAP with 100 DAP harvest' (I_3H_4) treatment whereas, the minimum values (10.00) was recorded from the combination of '3 Irrigation at 15, 45 and

60 DAP with 85 DAP harvest' (I_1H_1) treatment. The average tuber weight was observed the height in '5 Irrigation frequency' harvested at 100 DAP (35.60 g) while the lowest (27.57 g) was found on '3 Irrigation frequency' harvested at 85 DAP. The weight of tubers hill^{-1} was observed the maximum (435.38 g) in I_3H_4 treatment combination, while the minimum (275.70 g) was found on I_1H_1 treatment combination. The 5 irrigation frequency with harvested at 100 DAP attained the highest tuber yield (36.31 t ha^{-1}) whereas, the lowest yield (22.57 t ha^{-1}) was recorded in 3 Irrigation frequency with harvested at 85 DAP combination treatment. The maximum marketable yield of potato tuber (30.86 t ha^{-1}) was recorded from 5 Irrigation and harvested at 100 DAP while, the minimum (19.19 t ha^{-1}) was recorded from 3 Irrigation and harvested at 85 DAP. The highest non-marketable yield of potato tuber (5.45 t ha^{-1}) was recorded from 5 irrigation frequency with harvested at 100 DAP, while the lowest (3.39 t ha^{-1}) was recorded from 3 irrigation frequency with harvested at 85 DAP treatment combination. Among the 12 treatment combinations, '5 Irrigation frequency' exhibited the highest (1.070 g cm^{-3}) specific gravity at 110 DAP, while '4 Irrigation frequency' showed the lowest specific gravity (1.041 g cm^{-3}) at 85 DAP. '5 Irrigation' tubers exhibited the maximum (22.67 %) DM content at 100 DAP, while '3 Irrigation' showed the minimum (20.00 %) DM content at 85 DAP treatment combination. The highest TSS (5.73 %) was recorded from the combination of 3 Irrigation with '85 DAP' harvest (I_1H_1) treatment whereas, the minimum value (4.93 %) was found from 5 Irrigation with '100 DAP' harvest (I_3H_4) treatment. The highest starch content on potato (17.70 mg g^{-1} FW) was attained by I_3H_4 treatment combination and the lowest value (14.10 mg g^{-1} FW) was attained by I_1H_1 treatment combination. The maximum reducing sugar content (0.510 mg g^{-1} FW) was recorded in I_1H_1 treatment combination whereas, the minimum value (0.200 mg g^{-1} FW) was observed in I_3H_4 treatment combination. The highest canned production (9.08 t ha^{-1}) was observed in the combination of I_3H_4 treatment and the lowest value (5.64 t ha^{-1}) was recorded in the combination of I_1H_1 treatment. The highest (16.34 t ha^{-1}) flakes production exhibited by I_3H_4

treatment combination whereas, the lowest ones (10.16 t ha^{-1}) was exhibited by I_1H_1 treatment combination. The maximum (10.89 t ha^{-1}) chips production exhibited by I_3H_4 treatment combination and the minimum (6.77 t ha^{-1}) chips production was exhibited by I_1H_1 treatment combination.

Based on the experimental results, it may be concluded that-

i) Irrigation frequency and harvesting date had positive effect on growth characters, yield and qualitative attributes of potato.

ii) Application of 5 Irrigation at 15 DAP, 30 DAP, 45 DAP, 60 DAP and 75 DAPwith 100 DAP harvesting date combination seemed to be more suitable for getting higher tuber yield and quality.

Recommendation

To reach a specific conclusion and recommendation, more research work regarding different irrigation frequency and harvesting date on potato cultivation should be done in different agro ecological zones of Bangladesh.

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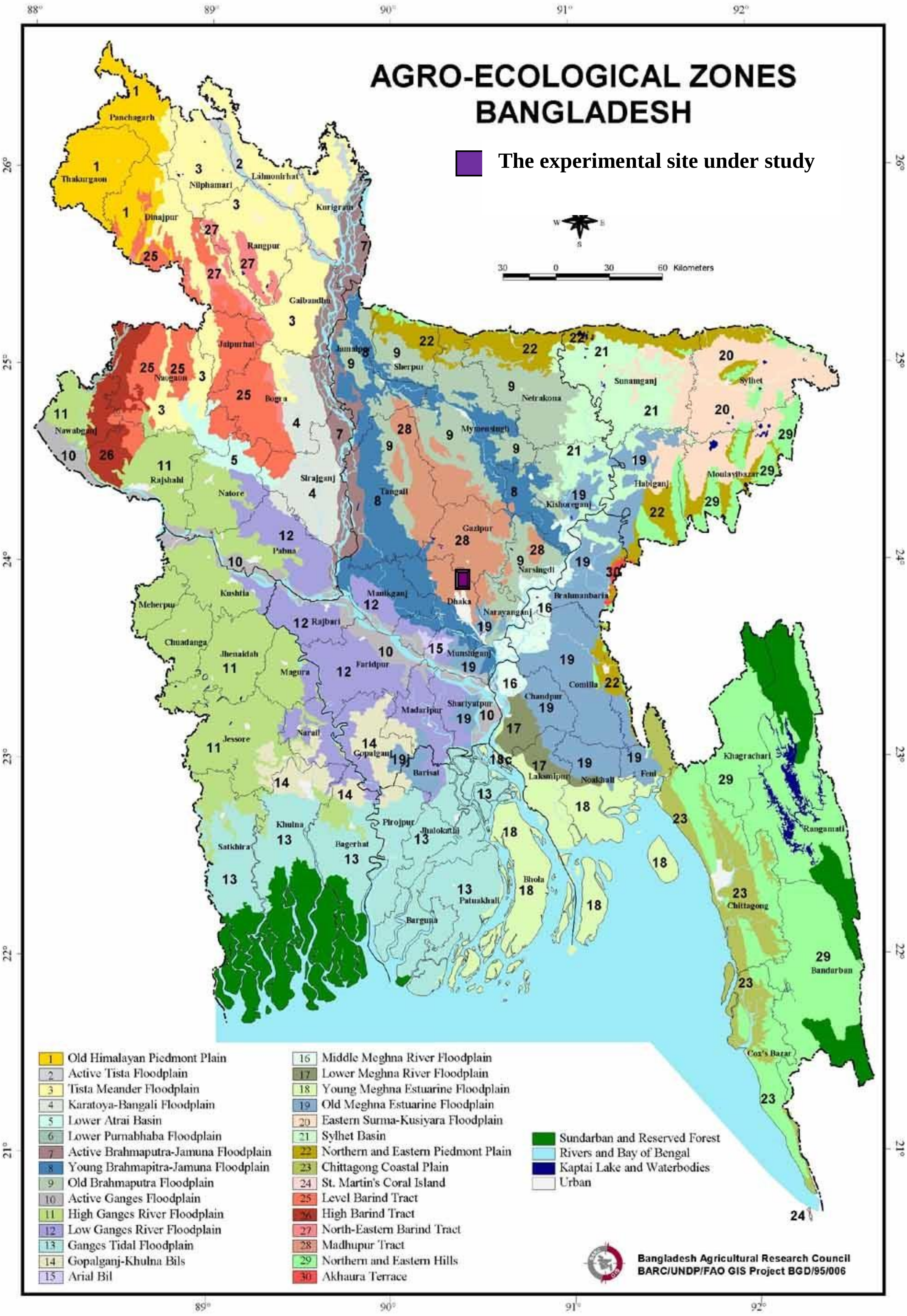
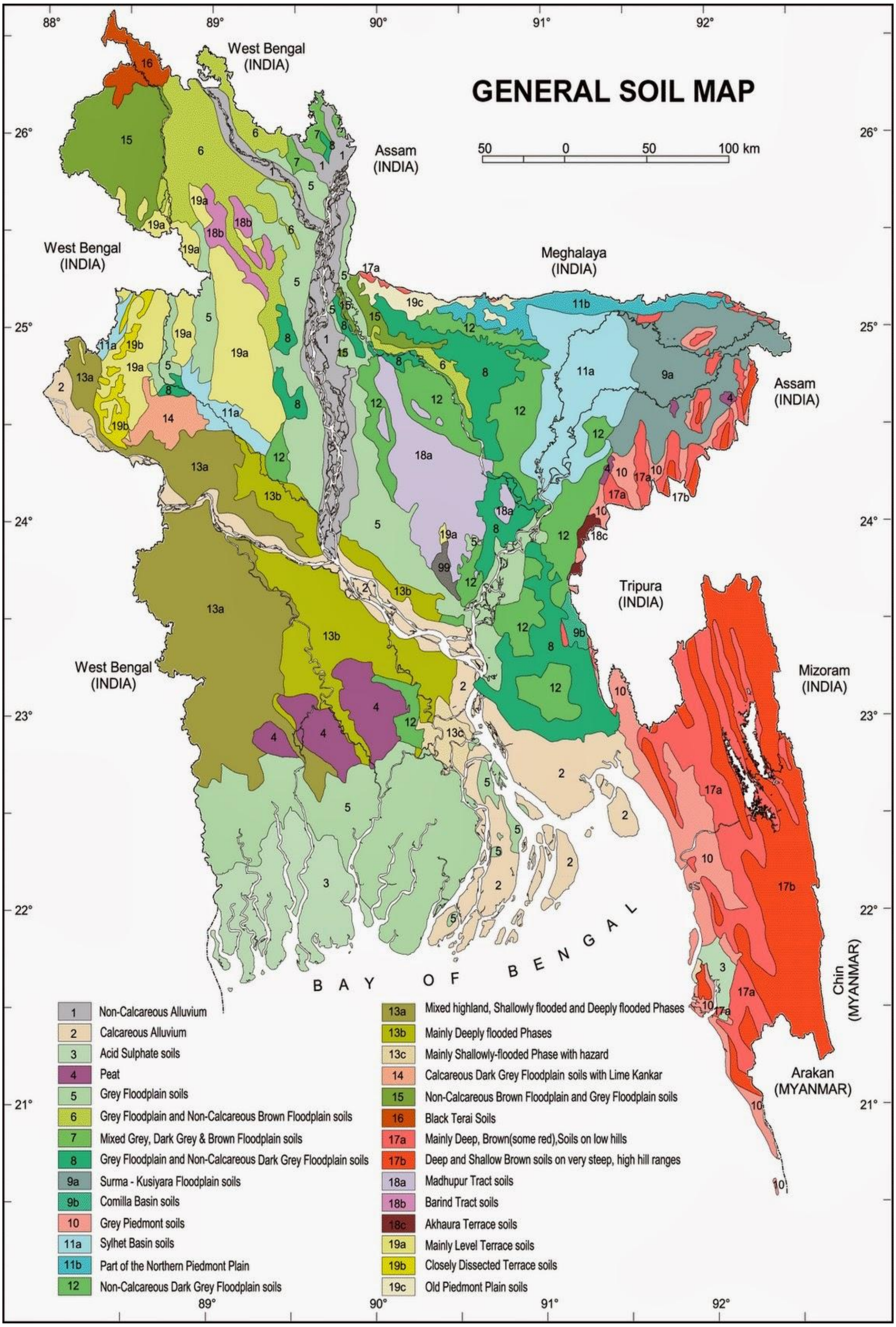
APPENDICES

Appendix I(A). Map showing the experimental sites under study



Appendix I(B). Map showing the general soil sites under study



Appendix II. Characteristics of soil of experimental site analyzed by Soil Resources Development Institute (SRDI), Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	**Characteristics**
Location	Experimental field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow Red Brown Terrace Soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	**Value**
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	6.0
Organic carbon (%)	0.69
Organic matter (%)	1.10
Total N (%)	0.06
Available P (ppm)	20.00
Exchangeable K (meq/100 g soil)	0.10
Available S (ppm)	22

Source: SRDI, 2019

Appendix III. Monthly average of Temperature, Relative humidity, total Rainfall and sunshine hour of the experiment site during the period from October 2020to March 2021

Year	**Month**	**Temperature**			**Relative Humidity (%)**	**Total Rainfall (mm)**	**Sunshine (Hour)**
		Max (°C)	**Min (°C)**	**Mean (°C)**			
2020	**October**	33	27	31	71	340.3	281
	November	32	23	28	54	0.60	347
	December	30	21	26	46	0.00	372
2021	**January**	30	20	26	40	2	367
	February	33	20	28	34	0.60	329
	March	39	24	33	41	6.3	370

AppendixIV. Analysis of variance (mean square) of days to first and last emergence

Source of variation	**Degrees of freedom**	**Days to first emergence**	**Days to last emergence**
Replication	2	10.021	12.250
Irrigation frequency (A)	2	10.583^{NS}	146.764^{NS}
Error (I)	4	1.771	58.194
A×B	6	3.824^{NS}	11.713^{NS}
Error (II)	18	2.417	14.903

* and ** indicates significant at 5% and 1% level of probability, respectively and NS = Non-significant.

AppendixV. Analysis of variance (mean square) of plant height at different DAP

Source of variation	Degrees of freedom	Plant height		
		30 DAP	50 DAP	70 DAP
Replication	2	5.852	80.983	156.225
Irrigation frequency (A)	2	10.897*	49.245*	170.324*
Error (I)	4	2.916	4.894	43.111
A×B	6	0.549**	3.452**	9.923**
Error (II)	18	1.305	8.520	29.517

* and ** indicate significant at 5% and 1% level of probability, respectively and NS = Non-significant.

AppendixVI. Analysis of variance (mean square) of number of leaves plant^{-1} at different DAP

Source of variation	Degrees of freedom	Number of leaves plant^{-1}		
		30 DAP	50 DAP	70 DAP
Replication	2	1.970	41.200	149.040
Irrigation frequency (A)	2	50.408*	119.856*	205.300*
Error (I)	4	2.805	15.578	11.556
A×B	6	0.577*	6.475*	3.825*
Error (II)	18	2.327	13.856	25.211

* and ** indicate significant at 5% and 1% level of probability, respectively

AppendixVII. Analysis of variance (mean square) of number of stem hill^{-1} at different DAP

Source of variation	Degrees of freedom	Number of stem hill^{-1}		
		30 DAP	50 DAP	70 DAP
Replication	2	0.030	0.043	0.007
Irrigation frequency (A)	2	0.362*	0.533*	0.645*
Error (I)	4	0.033	0.029	0.029
A×B	6	0.007*	0.070*	0.051*
Error (II)	18	0.017	0.039	0.045

* and ** indicate significant at 5% and 1% level of probability, respectively

AppendixVIII. Analysis of variance (mean square) of number of tuber hill^{-1}, average tuber weight and weight of tuber hill^{-1}

Source of variation	Degrees of freedom	No. of tuber hill^{-1}	Average tuber weight	Weight of tuber hill^{-1}
Replication	2	1632.998	0.239	7.238
Irrigation frequency (A)	2	2615.122*	13.411*	571.676*
Error (I)	4	616.838	1.677	2.702
Harvesting date (B)	3	5269.361^{NS}	16.141**	546.668**
A×B	6	302.044*	0.396*	8.145**
Error (II)	18	159.623	0.283	0.825

* and ** indicate significant at 5% and 1% level of probability, respectively and NS = non-significant.

AppendixIX. Analysis of variance (mean square) of yield

Source of variation	Degrees of freedom	Tuber yield	Marketable yield	Non-marketable yield
Replication	2	51.790	126.064	126.009
Irrigation frequency (A)	2	215.374*	19.650*	19.638**
Error (I)	4	9.512	85.745	85.754
Harvesting date (B)	3	204.549**	38.666*	38.647*
A×B	6	9.703*	6.316*	6.315*
Error (II)	18	2.516	7.787	7.785

* and ** indicate significant at 5% and 1% level of probability, respectively.

AppendixX. Analysis of variance (mean square) of the processing qualities of potato

Source of variation	Degrees of freedom	Specific gravity	Dry matter content	Total soluble solid	Starch content	Reducing sugar
Replication	2	4.596	1381.356	7342.477	10471.583	18040.750
Irrigation frequency (A)	2	1649.548^{NS}	717.850**	1824.473**	1845.217**	1972.878**
Error (I)	4	40.209	180.914	1371.893	348.417	8089.667
Harvesting date (B)	3	858.401^{NS}	2050.604**	1108.251**	1209.337^{NS}	121.435**
A×B	6	36.429^{NS}	183.522**	78.010**	610.261**	738.658**
Error (II)	18	30.629	404.774	1514.655	2879.208	10577.437

* and ** indicate significant at 5% and 1% level of probability, respectively and NS = Non-significant.

AppendixXI. Analysis of variance (mean square) of Grading of tuber plot^{-1}

Source of variation	Degrees of freedom	Grading			
		20-35 mm	35-45 mm	45-75 mm	> 75 mm
Replication	2	156.208	80.330	31.342	---
Irrigation frequency (A)	2	62.519**	65.135*	8.090**	
Error (I)	4	103.905	102.527	37.694	
Harvesting date (B)	3	3.558*	11.910*	2.122**	
A×B	6	3.345*	2.393*	1.673*	
Error (II)	18	20.387	48.889	20.423	---

* and ** indicate significant at 5% and 1% level of probability, respectively.

PLATES

Plate 1. Land preparation at experiment field

Plate 2. Tagging at experiment plot

Plate 3. Title of experiment

Plate 4. Potato tuber from treatment

Plate 5. Potato tuber from treatment