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Research Article

Seed tuber cutting improves tuber yield of potato (*Solanum tuberosum* L,) varieties under irrigation conditions in Dangla district of Amhara Region, Ethiopia

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Abstract: *Potato (Solanum tuberosum* L.*) is an important cash and food crop in Ethiopia. However, lack of planting material and improved varieties are among the major factors affecting its productivity. Therefore, an experiment was conducted at Gayeta Kebele of Dangla district, Awi Zone, Northwestern Ethiopia to study the effect of seed tuber cutting on yield and yield components of potato varieties under irrigated conditions. The experiment consisted of two improved varieties ('Belete' and 'Jalenie') along with one local variety and two tuber size categories and their half cuttings (whole large tuber (>75g), whole-medium tuber (39-75g), half cuttings of large tuber and half cuttings medium tuber. It was arranged with a factorial combination in RCBD with three replications. Phenological, growth, yield and quality parameters were significantly affected by the main factors (cutting and variety). Whole-large and half-large tuber sizes and Belete variety showed superior performance on marketable (38.24 t ha^{-1}) and total tuber yield (40.26 tha^{-1}) over the rest of the tuber sizes and varieties. The combination of Belete variety with whole-large seed tubers recorded the highest net benefit 261,516 ETB ha^{-1} with an acceptable marginal rate of return (113.6%). The second highest net benefit (247,001.3 ETB ha^{-1}) with an acceptable marginal rate of return (2566.67%) was recorded when Beltete variety was planted using half-large cut tubers. Hence, Belete variety with whole-large seed tubers, and half-large cut tubers could be recommended for resource-rich and poor farmers, respectively, for the production of potatoes under irrigated conditions in Gayeta kebele and areas with similar agro-ecology. Repeating the research in different seasons and locations is also recommended.*

Keywords: Keywords: Belete variety, Half-large tuber, Tuber size, Tuber yield
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1. Introduction

Potato is the fourth most important food crop in the world following rice, corn, and wheat (FAO, 2021). In the 2021 production season, the world's production reached nearly 376.2 million tons with a productivity of about 20.7 t ha^{-1}. According to FAO (2021), the 2021 potato production has increased by 17% compared with the 2000 production year. China is the leading country in the world with 94,362,175 tons of annual production, Africa`s potato production was about 28, 099,321.87 tones which is much lower than the quantity produced by China.

Potato was introduced to Ethiopia by a German botanist called Wilhelm Schimper in 1858 (Pankhurst, 1964**).** It is an important crop for smallholder farmers in Ethiopia serving both as a cash crop and food crop. It has the ability to provide income generation, double cropping advantages and its utilization in different forms, and a high yield product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops (Lung'aho *et al.*, 2007).

Ethiopia has suitable climatic and edaphic conditions for the production of high-yield and quality potatoes (Yilma, 1987). Potato is grown in four major areas: the central, the eastern, the northwestern, and the southern areas (CSA, 2010). The annual production of potatoes in the Meher season is around 1,141,856.23 tons with a productivity of 13.4 t ha^{-1} which is much lower than the world's average 20.7 t ha^{-1} (FAO**,** 2021). This indicates that Ethiopia's share of the world potato production is very low. The low yields are the result of a number of production constraints mainly involving abiotic and biotic stress factors. Among the biotic constraints late blight, bacterial wilt, virus diseases, and potato tuber moth constitute the major threats to potato production, while the abiotic stresses include soil nutrient deficiency, frost, drought, erratic rainfall, and air and soil high temperature especially in marginal areas **(**Gildemacher *et al.,* 2009).

About 31 potato varieties have been released by different research institutes in Ethiopia to address some of the production problems (MoANR, 2016). However, the majority of the farmers are growing old potato varieties, which is partly associated with a lack of seed tubers for the new varieties (Asredie *et al.,* 2015) and its high cost.

Potato tuber can be planted either whole-sized or by cutting tuber into smaller pieces (Bohl *et al.,* 2011). The same report indicated that planting large tubers will increase the yield which is associated with increased cost of production. Smallholder farmers traditionally use 20-25 quintals of seed tubers per hectare which incurred additional seed cost. In this regard, EIAR (2007) recommended 18 to 20 quintals of potato seed tubers per hectare. So planting cut tubers reduces seed costs. Therefore, the use of cut seed tubers as planting material may help to reduce seed costs. Cut seed tubers however should contain at least one to two buds (Taye *et al.*, 2013). Using cut-seed tubers is often associated with disease transmission which requires due attention. Using sterilized equipment for cutting and treating the cut tubers with either synthetic or natural chemicals reduces disease transmission during the cutting processes (Strange and Blackmore, 1990).

The cost of seed tubers accounts for the major production costs of potatoes. Accordingly, Vander Zaag and Demagante (1989) the use of cut seed tubers as planting materials helps to reduce the overall production costs of potatoes. Cutting a seed tuber into two or three pieces and using them as planting material consistently resulted in increased numbers of main stems and tuber yield (Taye *et al.*, 2013). Similarly, small-sized tuber size and half-cut distal tubers were reported to be economically profitable for production of potatoes (Hossain *et al.*, 2011). According to Chethan *et al*. (2023), planting cut tubers from existing planters with 0°–180° angles orientation gives better plant emergence and average tuber yield which is statistically comparable with that of the yield obtained from the whole tuber planting.

However, in Ethiopia, information about the use of cut seed tubers as planting materials for potato production is scarce. Therefore, this research was undertaken to evaluate seed tuber cuts of potato varieties as planting materials in Dangla district of Awi Zone, Amhara Region, Ethiopia.

2. Materials and Methods

2.1. Description of the study area

The study was conducted during the 2019/20 irrigation season in Gayeta Kebele, Dangla district, Awi Zone, northwest Ethiopia. The altitude of the site is 2184 m.a.s.l. It is located at $11^0$12'23" N latitude and $36^0$51'35" E longitude (Figure 1).

The soil type of the study area is nitrosols (Mehretie and Wondeamlak, 2013). The rainfall pattern is unimodal with long rainfall stretching from June to October. Based on the information obtained from the Ethiopian Metrological Agency Dangla Station in 2018 (personal information), the Dangla district receives 1716 mm annual rainfall with 25.5 ℃ and

10 °C mean annual maximum and minimum temperatures, respectively.

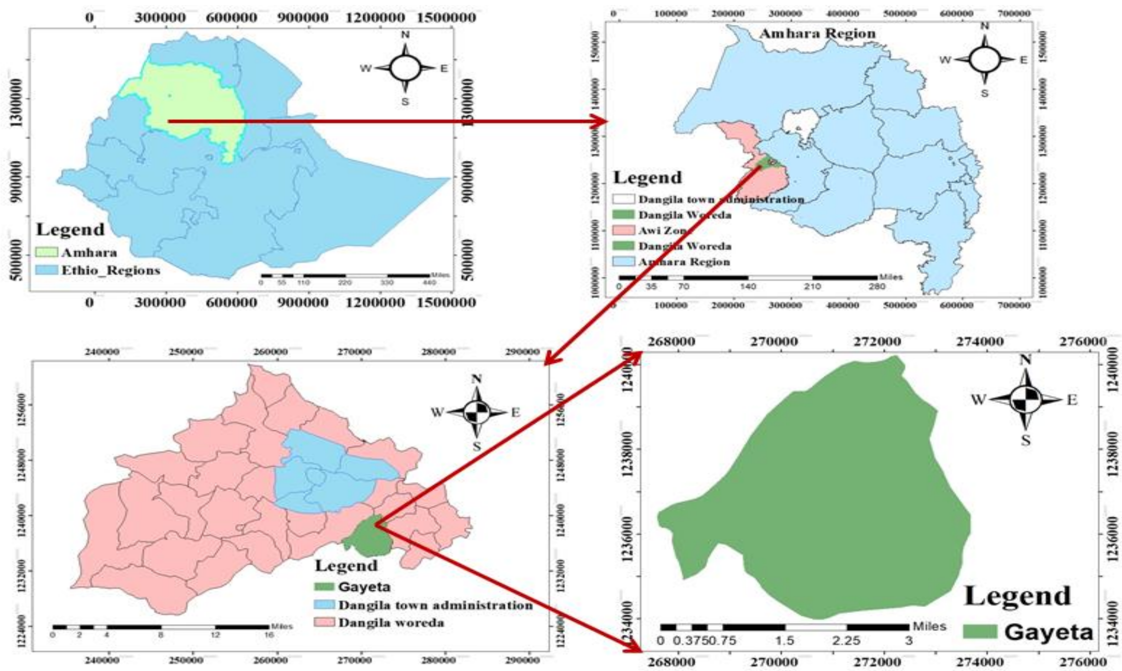

Figure 1: Location map of the study area

2.2. Experimental materials

Jalenie and Belete improved potato varieties as well as the local variety "Ater Abeba/Key denich used as a test crop. The varieties are commonly produced by smallholder farmers in the study area. Jalenie and Belete varieties were released by the Holetta Agricultural Research Centre in 2002 and 2009, respectively (MoANR, 2016). The seeds of these varieties were obtained from the Adet Agricultural Research Center.

2.3. Experimental treatment, design and procedures

The experimental treatments consisted of three potato varieties (Belete, Jalenie and local) and four seed tuber sizes (whole-large seed tuber (>75g), whole-medium (39-75g), half-large, half-medium). The size of the seed tuber was determined based on the size category proposed by Lung'aho *et al*. (2007). The treatments were arranged with 3 x 4 factorial combinations in RCBD with three replications. There were 12 treatment combinations and 36 experimental units. A relatively uniform seed weight with a maximum variation of 5g was used. Each seed piece contained at least four "eyes"/ buds. Cutting was done using a knife. The knife was treated with 95% alcohol after each cut to prevent disease transmission between seed tubers. After cutting the tubers into sections, they were placed in a humid location until planted to reduce higher transpiration.

The plot size was 9 m^2 (3.0m x 3.0m) and contained four rows, which accommodated 10 plants per row and 40 plants per plot. The spacing between block and plot was 1 m and 0.5 m, respectively.

2.4. Management of experimental plants

The land was ploughed to a depth of 25-30 cm for six times. Healthy and well-sprouted tubers of potato varieties were planted under irrigation on December 24, 2019, with a spacing of 75 cm between ridges and 30 cm between tubers. The furrow irrigation method with 7-day watering intervals was used (MoANR, 2011). Recommended rates of NPS (195 kg ha^{-1}) and Urea (165kg ha^{-1}) were applied (MoANR, 2016). NPS was applied once at the time of planting whereas, urea was applied with three splits; the first one-third at the time of planting, the second one-third two weeks after emergence and the third one-third at the initiation of flowering. Weeding and earthing up were carried out uniformly for all treatments. Ridomil MZ 63.5% WP (3 kg ha^{-1}) and Mancozeb 80% WP (1.5 kg ha^{-1}) with the rates of 3.0 kg ha^{-1} and 1.5 kg ha^{-1}, respectively, were applied to manage fungal diseases (EARO, 2004).

2.5. Data collection

Phenological parameters (plant emergence, flowering and maturity) were collected using the procedures used by Alemayehu and Jemberie (2018). Growth parameters (plant height, number of main stems per plant) were recorded during the vegetative growth stage (Lung`aho *et al.*, 2007). Average tuber number per plant, average tuber yield (kg/plant), tuber size distribution in percentage, marketable tuber yield (t ha^{-1}), unmarketable tuber yield in percentage, and total tuber yield (t ha^{-1}) were recorded at harvesting from net plot 3.6 m^2. Quality parameters such as specific gravity (Gould, 1995) and dry matter content (Tesfaye *et al.*, 2012) were taken after harvesting based on the following formulas.

$$Specific\ gravity = \frac{\text{Weight in air}}{(\text{Weight in air} - \text{weight in water})} \quad [1]$$

$$Dry\ Matter = \left(\frac{\text{Dry weight}}{\text{Fresh weight}}\right) * 100 \quad [2]$$

2.6. Data analysis

The data were subjected to a two-way analysis of variance (ANOVA) at a significance level of (α=0.05) (Gomez and Gomez, 1984). Following the ANOVA result, mean separation was carried out through the LSD method at a 5% level of significance for significant responses by using the SAS 9.0 statistical software package (SAS Institute, 2002).

2.7. Economic analysis

Partial budget analysis was done using the methodology described by CIMMYT (1988) to evaluate the profitability of the treatments. The procedure considers the analysis of gross benefit (GB), total variable cost (TVC), net benefits (NB) and finally the analysis of marginal rate of return (MRR). To narrow the yield gap between experimental plots and farmer's fields, the marketable tuber yield was adjusted down to 90%. Net benefit was calculated by subtracting the total variable cost of production from the gross benefit. Seed cutting cost (250- per man-day) and seed cost of Belete, Jalenie and Ater Abeba/Key dench varieties were 12 Eth-Birr kg^{-1}, 10 Eth-Birr $kg^{-1}$and 8 Eth-Birr kg^{-1}, respectively.

Dominance analysis was performed after arranging the treatments in terms of increasing variable costs. A treatment is dominated when it has a higher cost but a lower net benefit than any preceding treatment. Finally, the marginal rate of returns (MRR) was calculated for the non-dominated treatments, where the percentage change in benefit over the change in total variable cost in moving from a lower-cost treatment to a higher one.

3. Results and Discussion

3.1. Phenological parameters

3.1.1. Days to 50% emergence

Variety had a significant effect on days to 50% emergence ($P< 0.0001$). However, seed tuber and its interaction with variety had no significant effect on days to 50% emergence. The average number of days to get 50% emergence for all the tested varieties ranged from 16.0 ± 0.6 to 18.7 ± 0.3 days. Ater Abeba took the shortest time (16.4 days) followed by Jalenie (18 days) and Belete (18.2 days) to emerge from the soil (Table 1). The results of this study indicated that emergence was varied among potato varieties. This could be attributed to the genetic makeup of potato varieties (Chindi *et al.*, 2020). According to Tilahun *et al.* (2018) and El-Abd *et al.* (2013), genotype differences significantly influence the days required to attain 50% emergence. The same reports also indicated that the longest days required to attain 50% emergence were recorded on Belete while the earliest in local varieties (Ater Abeba), which is similar to the current study. The difference in days to 50% emergence observed in the present study could be associated with the genetic makeup of the varieties and the environmental conditions. The local variety used in the study might have adapted to the environmental conditions, which may have accelerated the emergence of the variety compared to the improved varieties (Belete and Jalenie).

3.1.2. Days to 50% flowering

Variety had a significant effect on days to 50% flowering ($P< 0.0001$). However, seed tuber size and its interaction with variety had no significant effect on days to 50% flowering. The average number of days to get 50% flowering for all the tested varieties ranged from 59.7 ± 1.8 to 79.7 ± 0.3 days. Jalenie (77.92 days) and Belete (78.9 days) required a longer time to reach 50% flowering compared to Ater Abeba (60.33 days) variety (Table 1). The difference in flowering of potato varieties could be attributed to the genetic variation and environmental adaptability among the varieties. Accordingly, some researchers reported that earliness in flowering is controlled by many factors including genetic and environmental factors mainly temperature and light (Vreugdenhil, 2007; Kena, 2018). This could be the reason why the local variety flowered earlier compared to improved varieties in the current study.

3.1.3. Days to maturity

Seed tuber types (*P< 0.037*) and variety (*P< 0.0001*) had a significant effect on days to 90% maturity. On the other hand, their interaction had no significant effect on days to 90% maturity. All of the treatments attend 90% maturity within a range of 86.3 ± 0.7 to 117.3 ± 1.7 days. Aster Abeba matured early (87.3 days) compared to Belete (114.1 days) and Jalenie (115.8 days) (Table 1). Similarly, Tilahun *et al.* (2018) reported that Belete variety required the highest average number of days to attain maturity compared to the local variety, Ater Abeba. Potatoes which emerged and flowered earlier also matured earlier than those that emerged and flowered later. Genotype differences and environmental conditions also could influence the number of days required to attain maturity in different research (Vreugdenhil, 2007, Tilahun *et al., 2018*, Kena, 2018).

Large half-cut and whole medium tubers took statistically similar average number of days to reach maturity; however, whole large tubers reached maturity earlier than large half-cut tuber sizes (Table 1). Similarly, Ebrahim *et al*. (2018) reported plants grown from large-sized seed tubers matured earlier than that of small-sized seed tubers. Early maturing potatoes will have a positive influence on the rural community to alleviate seasonal food shortages and quick economic return.

Table 1: Phenological parameters of potato as influenced by variety and type of seed tuber

Variety	Days to 50% emergence	Days to 50% flowering	Days to 90% maturity
Belete	18.17[a]	78.92[a]	114.08[a]
Jalenie	18.00[a]	77.92[a]	115.83[a]
Ater Abeba	16.42[b]	60.33[b]	87.25[b]
LSD (0.05)	0.6900	1.5364	2.0338
Type of seed tuber			
Whole large	17.556	72.333	106.67[a]
Whole medium	17.667	72.222	107.22[a]
Large half cut	17.556	72.556	105.11[ab]
Medium half cut	17.333	72.444	103.89[b]
LSD (0.05)	Ns	Ns	2.3484
CV%	4.56	2.77	2.36

Means followed by the same letter (s) within a column are not significantly different at a 5 % level of significance. LSD = least significant difference and CV = coefficient of variation, Ns = not significant

3.2. Growth parameters

3.2.1. Plant height

Potato variety significantly influenced the average plant height (*P < 0.0001*) while seed tuber type and its interaction with variety did not influence the average plant height. Belete (67.7cm) and Jalenie (67.2cm) varieties recorded the longest plant heights compared to Ater Abeba (54.9 cm) (Table 2). The possible governing factors on differences in number of main stems per plant between potato varieties might be associated with genetic potential in the number of buds per tuber (Morena *et al.*, 1994).

3.2.2. Average number of main stems per plant

The type of seed tuber (*P< 0.0048*) and variety (*P< 0.0001*) of potato had a significant effect on average main stem numbers per plant while their interaction did not influence this parameter. The number of main stems per plant of potato varieties ranged from 2.33 to 3.1. Jalenie (3.1 stems) and Belete (3.0 stems) varieties produced the highest number of main stems per plant than Aster Abeba (2.3 stems) variety (Table 2). The number of viable sprouts at planting, sprout damage at the time of planting and growing conditions has a direct influence on the number of main stems per plant (Morena *et al.,* 1994). In this regard, during sowing, Jalenie variety seed tubers had a higher number of buds and sprouts, which might consequently result in a higher number of main stems per plant.

The highest number of main stems per plant was obtained from whole large-sized tubers (3.14) followed by whole medium tuber (2.81), half large (2.72) and half medium (2.58) cut tubers, respectively (Table 2). The highest number of main stems in whole large-sized seed tubers observed in the present study could be due to the availability of a greater number of eyes per tuber in large-sized seed tubers than other seed tuber types which consequently resulted in the higher number of main stems per plant. A direct relationship between seed tuber size and number of stems per plant was also reported by Hossain et al. (2011) and Asnake *et al*. (2023).

Table 2: Plant height and average number of main stems of potato as influenced by variety and type of seed tuber

Variety	Plant height (cm)	Average No main stem
Belete	67.71[a]	3.00[a]
Jalenie	67.16[a]	3.10[a]
Ater Abeba	54.94[b]	2.33[b]
LSD (0.05)	4.5693	0.2425
Type of seed tuber		
Whole-large	66.950	3.14[a]
Whole-medium	64.319	2.81[b]
Large-half cut	60.236	2.72[b]
Medium-half cut	61.569	2.58[b]
LSD (0.05)	NS	0.2800
CV%	8.45	10.68

Means followed by the same letter (s) within a column are not significantly different at a 5 % level of significance. LSD = least significant difference, and CV = coefficient of variation

3.3. Yield parameters

3.3.1. Average tuber number per plant

The ANOVA results showed that the type of seed tuber had a significant effect on the average number of tubers per plant (*P < 0.0001*). However, the average number of tubers per plant was not influenced by potato variety and its interaction with the type of seed tuber. The average tuber number per plant for the tested varieties ranged between 24.7 and 25.9. The highest number of tubers per plant was observed from whole large-sized tuber (28.5) and whole medium-sized tubers (27.3) compared to half-large (22.6) and half-medium (22.6) seed tubers (Table 3). The results of the present study clearly showed that the average number of tubers increased as the seed tuber size increased. Accordingly, the presence of numerous eyes on large-sized tubers leads to the production of several stems that produce more tubers and consequently higher total tuber yield. Hossain *et al.* (2011) also recorded the highest number of tubers per plant when large-size-whole tubers were used as planting materials.

3.3.2. Average tuber yield per plant

Variety had a significant effect on the average tuber yields per plant (*P < 0.0001*), whereas, the type of seed tuber and its interaction with variety had no significant effect on the average tuber yield per plant of potato. Belete variety produced the highest average tuber yield per plant (1.76 kg) compared to Jalenie (1.24 kg) and Ater Abeba (1.16 kg) varieties (Table 3). These variations in average tuber yield per plant might be associated with an inherited potential of the genotypes (Gebreselassie *et al.,* 2016). Whole large seed tubers produced statistically similar average tuber yields to half-large seed tubers. So, using half-large seed tubers might help to reduce the seed cost by half compared to the use of a whole large seed tuber as planting material.

Table 3: Average tuber number and yield of potato among variety and type of seed tuber

Variety	Average tuber number per plant	Average tuber yield/plant
Belete	25.90	1.76[a]
Jalenie	25.11	1.24[b]
Ater Abeba	24.73	1.16[b]
LSD (0.05)	NS	0.2486
Type of seed tuber		
Whole-large	28.52[a]	1.46
Whole-medium	27.28[a]	1.38
Large-half cut	22.61[b]	1.32
Medium-half cut	22.57[b]	1.40
LSD (0.05)	1.8752	NS
CV%	7.29	22.02

Means followed by the same letter (s) within a column are not significantly different at a 5 % level of significance.

LSD = least significant difference, and CV = coefficient of variation

3.3.3. Tuber size distribution

Variety had a significant effect on large-sized tubers (*P < 0.0001*), medium-sized tubers (*P < 0.0357*) and small-sized tubers (*P < 0.0026*). However, the type of seed tuber and its interaction with variety did not significantly influence the distribution into large-sized, medium-sized and small-sized tubers. Large-, medium-, and small-sized tuber yields were varied among the tested potato varieties. Belete variety produced the highest proportion of large-sized tubers (46.45 %) followed by the Jalenie variety (41.45%) and Ater Abeba variety (25.9%). In contrast, Aster Abeba variety produced the highest proportion of small-sized tubers (25.29%) and medium-sized tubers (48.80%) (Table 4). The lowest proportion of small-sized tubers was produced from the Jalenie variety (14.34%) and Belete variety (17.04%), which were statistically different when compared to each other (Table 4). Similar results were also reported by various researchers where the genetic makeup of varieties influences the tuber size distribution in potatoes (Chala and Dechassa, 2015, Bilate and Mulualem, 2016, Gebreselassie *et al.*, 2016, Tilahun *et al.*, 2018, Tilahun and Haile, 2019).

Table 4: Seed tuber size distribution as influenced by potato varieties

Variety	Small-sized (%)	Medium-sized (%)	Large-sized (%)
Belete	17.04^{b}	36.51^{b}	46.45^{a}
Jalenie	14.34^{b}	44.22^{ab}	41.45^{b}
Ater Abeba	25.29^{a}	48.80^{a}	25.91^{c}
LSD (0.05)	3.6395	5.3732	2.4170
CV%	37.40	24.34	12.45
Type of seed tuber			
Whole-large	21.32	41.76	36.91
Whole-medium	19.86	43.41	36.74
Large-half cut	18.72	46.39	34.89
Medium-half cut	15.69	40.67	43.64
LSD(0.05)	NS	NS	NS
CV%	37.40	24.34	12.45

Means followed by the same letter (s) within a column are not significantly different at a 5 % level of significance. LSD = least significant difference, and CV = coefficient of variation

3.3.4. Marketable tuber yield

Type of seed tuber (*P < 0.049*) and variety (*P < 0.0001*) had a significant effect on marketable tuber yield of potato. However, the interaction of the type of seed tuber and variety did not significantly affect marketable tuber yield. The marketable tuber yield for all the tested varieties ranged from 26.0 to 38.2 t ha^{-1}. Belete variety produced the highest marketable tuber yield (38.2 t ha^{-1}) compared to the Jalenie (31.7 t ha^{-1}) and Ater Abeba (26 t ha^{-1}) varieties (Table 5). In general, the present study indicated that the improved varieties produced more marketable tuber yield compared to the local variety. Variations on marketable tuber yield of different potato varieties were reported by several researchers (Bilate and Mulualem, 2016, Tilahun *et al.*, 2018 and Tessema *et al.*, 2019).

In terms of seed type, whole-large seed tuber produced the highest marketable tuber yield (34.5 t ha^{-1}) while medium-half seed tuber (30.8 t ha^{-1}) produced the lowest marketable yield, which was statistically similar to marketable yields recorded from another type of seed tubers (Table 5). Gutema (2016) reported significant variation in marketable tuber yield between the whole, and half-cut, seed tubers.

Large-sized seed tubers generally contain more buds compared to medium-sized and cut tubers, which resulted in relatively more sprout and food resources and consequently more stems per plant as observed in the present study. The high number of main stems per plant is associated with enhanced photosynthetic activity and accumulation of more assimilate, which in turn results higher tuber yield.

3.3.5. Unmarketable tuber yield

The type of seed tuber (*P < 0.0013*) and variety (*P < 0.0001*) had a significant effect on the unmarketable tuber yield of potato. However, the interaction of seed tuber type with variety did not significantly influence unmarketable tuber yield. The average proportion of unmarketable tuber yield for all the tested varieties ranged from 5.0 to 20.9% where the local variety (Ater Abeba) produced the highest unmarketable tuber yield (20.88%) compared to Belete (5.04%) and Jalenie (10.10%) varieties. Generally, improved varieties recorded the lowest percentage of unmarketable yield compared to the local variety in the present study. These results are in line with the findings of other scholars who reported that potato varieties differ in their unmarketable tuber yield, which may arise from the genetic makeup of the varieties (Mulualem, 2016, Tilahun *et al.*, 2018, Tessema *et al.*, 2019).

Half-large tuber produced the highest proportion of unmarketable tuber yield (13.58%) compared to the whole large tuber (9.43%) (Table 5). With the increase in seed tuber size, there was a decreased proportion of unmarketable tuber yield in the present study. This could be due to the presence of high reserve food in large-sized tubers which facilitate the vegetative growth and tuber development that in turn reduces unmarketable tuber yield. Similar results were reported by Verma *et al.* (2007) and Ebrahim *et al*. (2018) which highlighted the production of the highest unmarketable tuber yields from small-sized seed tubers while the lowest unmarketable tuber yield from large-sized seed tubers.

3.3.6. Total tuber yield

The ANOVA results showed that variety had a significant effect on total tuber yield ($P < 0.0001$) while the type of seed tubers and its interaction with variety did not influence the total tuber yield. The total tuber yields for all the tested varieties ranged from 32.7 to 40.3 t ha^{-1}. The highest total tuber yield was produced from Belete (40.26 t ha^{-1}) variety followed by the Jalenie variety (35.16 t ha^{-1}) and Aster Abeba variety (32.71 t ha^{-1}) (Table 5). Improved varieties of potato produced higher total tuber yield compared to local varieties which could be associated with the genetic potential of the varieties (Gebreselassie *et al.*, 2016; Tessema *et al.*, 2019). Even if the total tuber yield among the type of seed tuber is statistically insignificant, using half-cut seed tuber may contribute to the reduction of seed cost which is relatively high in potato production.

Table 5: Tuber yield of potato as influenced by variety and type of seed tuber

Variety	Marketable yield (t ha^{-1})	Unmarketable yield (%)	Total yield (t ha^{-1})
Belete	38.24^{a}	5.04^{c}	40.26^{a}
Jalenie	31.67^{b}	10.10^{b}	35.16^{b}
Ater Abeba	25.95^{c}	20.88^{a}	32.71^{b}
LSD (0.05)	2.6505	1.7605	2.6624
Type of seed tuber			
Whole-large	34.53^{a}	9.43^{b}	39.91
Whole-medium	30.94^{b}	12.26^{a}	34.95
Large- half	31.57^{ab}	13.58^{a}	36.21
Medium-half	30.77^{b}	12.76^{a}	35.09
LSD (0.05)	3.0605	2.0328	NS
CV%	9.47	16.81	8.40

Means followed by the same letter (s) within a column are not significantly different at a 5 % level of significance. LSD = least significant difference and CV = coefficient of variation

3.4. Tuber quality parameters

3.4.1. Specific gravity

Variety had a significant effect on specific gravity ($P < 0.0193$). However, the type of seed tuber and its interaction with variety had no significant effect on the specific gravity of the potato. The average specific gravity for all the tested varieties ranged from 1.06 to 1.08 kg m^{-3}. Belete variety produced the highest specific gravity (1.08 kg m^{-3}), compared to the rest of the varieties (Table 6). Similar studies reported that variety influences the specific gravity, which is in agreement with the findings of the present study (Addisu *et al*., 2014, Bilate and Mulualem, 2016, Habtamu *et al.*, 2016, Mohammed, 2016, Tessema *et al.*, 2019).

Potatoes with a specific gravity greater or equal to 1.08 kg m^{-3} are generally suitable for the processing industry (Lefort *et al.*, 2003 and Tesfaye *et al.*, 2013) while those varieties with less than 1.07 kg m^{-3} specific gravity are not unacceptable for processing industry (CIP, 2007). According to Rommens *et al*. (2010), tubers with high specific gravity are appropriate for French fries or chips production as they have less oil absorption and better texture. In this regard, Belete variety could be acceptable for the processing industry.

3.4.2. Dry matter content

The ANVOA results showed that variety had a significant effect on tuber dry matter content ($P < 0.0001$) while the type of seed tuber and its interaction did not influence this parameter of potato. The dry matter content of the tested varieties ranged from 19.5 to 25.3%. Although the lowest specific gravity, Ater Abeba (DMC = 25.29) recorded the highest dry matter content while the Jalenie variety (DMC = 19.51) recorded the lowest dry matter content (Table 6). Measurement of the specific gravity of potatoes has been widely used as a tool for quick estimation of dry matter and starch content in potato tuber lots (Kaur and Aggarwal, 2014). According to Wilson *et al*. (1969), the relationship between dry matter and specific gravity is hyperbolic, but, for values of dry matter percentage usually encountered with potatoes, a linear approximation is adequate. This could be attributed to the specific gravity of a tuber depends not only on the percentage of dry matter but also on the density of the dry matter and the percentage of air in the tissue, which depends on the genetic makeup of potato varieties (Tsegaw and Hammes, 2005; Chala and Dechassa, 2015; Bilate and Mulualem, 2016).

Table 6: Specific gravity (g cm^{-3}) and dry matter content (%) between varieties and types of seed tuber

Variety	Specific gravity	Dry matter
Belete	1.08^{a}	24.21^{a}
Jalenie	1.07^{ab}	19.51^{b}
Ater Abeba	1.06^{b}	25.29^{a}
LSD	0.0135	1.4726
Type of seed tuber		
Whole large	1.0774	23.506
Whole medium	1.0760	22.939
Large half cut	1.0806	22.989
Medium half cut	1.0717	22.584
LSD (0.05)	NS	NS
CV%	1.46	7.43

Means followed by the same letter (s) within a column are not significantly different at a 5 % level of significance. LSD = least significant difference and CV = coefficient of variation

3.5. Economic analysis

3.5.1. Partial budget analysis

The partial budget analysis showed that the highest net benefit (261,516 ETB ha^{-1}) was recorded when Belete variety was planted using whole-large seed tuber followed by the treatment combination of Belete variety and half-large seed tuber. On the other hand, the lowest net benefit (138,279 ETB ha^{-1}) was recorded from the treatment combination of local variety with half-large seed tuber (Table 7).

3.5.2. Partial budget analysis

The marginal rate of return was calculated as a change of net benefit divided by the change of variable costs of the treatment. As indicated by CYMMIT (1988) when the net benefit of a given treatment is less than the preceding treatment by increased variable cost, this treatment is then dominated and is not considered in MRR analysis. Accordingly, half-large cut tuber of Belete variety (2566.67%) recorded the highest marginal rate of returns followed by half-large cut tubers of Jalenie variety 2400% and half medium-cut tuber of local variety (2233%) (Table 8). This indicates that investing one Ethiopian Birr in the treatment combination of half-large seed tuber and Belete variety will result in a net benefit of 25.67 Ethiopian Birr.

Table 7: Partial budget analysis of potatoes as influenced by types of seed tuber and varieties

Treatment combinations	TVC (ETB ha^{-1})	MTY (t ha^{-1})	AJMTY (t ha^{-1})	GB (ETB ha^{-1})	NB (ETB ha^{-1})
Local x MHC	15567	27.1	24.39	170730	155163
Local x LHC	14811	24.3	21.87	153090	138279
Jalenie x MHC	17864	28.2	25.38	190350	172486
Jalenie x LHC	19187	33.1	29.79	223425	204238
Belete x MHC	22242.7	37.01	33.309	266472	244229.3
Belete x LHC	22350.7	37.41	33.669	269352	247001.3
Local x WM	22561	24.3	21.87	153090	130529
Local x WL	23600.5	28.15	25.335	177345	153744.5
Jalenie x WM	28402.4	31.12	28.008	210060	181657.6
Jalenie x HL	29234	34.2	30.78	230850	201616
Belete x WM	34076.4	37.32	33.588	268704	234627.6
Belete x WL	35124	41.2	37.08	296640	261516

Note: Labor cost for seed cutting = 250 ETB man-day^{-1}; seed cost of Belete, Jalenie and Ater Abeba/Key dench varieties were 12 ETB kg^{-1}, 10 ETB kg^{-1} and 8 ETB kg^{-1}, respectively; MHC = Medium-half cut; LHC = large-half cut; WM = Whole-medium; WL = Whole large; TVC = Total Variable Cost; GB = Gross Benefit; NB = Net Benefit

Table 8: Marginal rate of return as influenced by type of seed tubers and variety of potato

Treatment combinations	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Dominance	MRR %	Rank
Local x LHC	14811	138279		-	
Local x MHC	15567	155163		2233	3
Jalenie x MHC	17864	172486		754	5
Jalenie x LHC	19187	204238		2400	2
Belete x MHC	22242.70	244229.30		1308.74	4
Belete x LHC	22350.70	247001.30		2566.67	1
Local x WM	22561	130529	D		
Local x WL	23600.50	153744.50	D		
Jalenie x WM	28402.40	181657.60	D		
Jalenie x WL	29234	201616	D		
Belete x WM	34076.40	234627.60	D		
Belete x WL	35124	261516		113.63	6

LHC = large-half cut; MHC = Medium-half cut; WM = Whole-medium; WL = Whole large; TVC = Total Variable Cost; GB = Gross Benefit; NB = Net Benefit

4. Conclusion

The results of the present study clearly showed that variety and types of seed tuber influenced most of the tested phenological, growth, yield and quality-related parameters of potatoes. Generally, improved varieties used in the present study performed well in almost all the tested parameters compared to the local variety. Belete variety produced the highest marketable tuber yield (38.24 t ha^{-1}) and specific gravity (1.08 kg) while the local variety 'Ater Abeba' produced the lowest marketable tuber yield (25.95 t ha^{-1}) and specific gravity (1.06 kg). The whole large-sized tuber recorded the highest marketable tuber yield (34.53 t ha^{-1}) and the lowest proportion of unmarketable tuber yield (9.43%). Belete variety planted with the whole-large tuber recorded the highest net benefit (261,516 ETB ha^{-1}) with an acceptable level of MRR (113.63%). This variety also produced the second highest net benefit (247,001.3 ETB ha^{-1}) with an acceptable level of MRR (2566.67%) when planted with half large-cut tubers. On the other hand, local variety, Ater Abeba recorded the lowest net benefit (157,097 Birr ha^{-1}) when planted with half-medium cut seed tuber. Hence, Belete variety in combination with whole-large seed tuber could be recommended for resource-rich farmers. However, for resource-poor farmers, half-large cut seed tuber of Belete variety could be used as planting materials for the production of potatoes under irrigation conditions in Dangla District and areas with similar agroecology. Repeating the research in different seasons and locations is also recommended.

Data availability statement

Data will be made available up on request.

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Conflicts of interest

The authors declared that there is no conflict of interest.

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