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Potato (*Solanum tuberosum* L.) yield and quality as influenced by cultivar and nitrogen fertilizer levels at Wolaita Sodo, Ethiopia

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Abstract

Despite the food and nutritional contribution of potatoes, their production and productivity are faced with major constraints such as selection of an appropriate cultivar and fertilizer rates. A field experiment was conducted at Wolaita Soddo, in Southern Ethiopia, to identify adaptable cultivars and optimum levels of nitrogen fertilizer for potato production. The treatments consisted of three cultivars (Bellete, Gudene, and one local check) and four levels of nitrogen (N) (0, 55.5, 111, and 166.5 kg N ha^{-1}) to give a total of 12 treatments arranged in factorial combinations and laid out in a Randomized Complete Block Design with three replications. Data was collected on growth, yield, and yield components. Results revealed that days to 50% flowering and maturity, number of marketable tubers, unmarketable tubers, marketable tuber yield, and total tuber yield were significantly influenced by the interaction effect. As the level of N increased from 0 to 166.5 kg ha-1, the days to physiological maturity were extended. The maximum marketable yield (34.15 t ha^{-1}) was recorded from cultivar Bellete with 166.5 kg N $ha^{-1,\ whereas}$ the least (7.48 t ha^{-1}) was obtained from local check with 0 kg N ha-1, indicating a 356.55% yield advantage with proper cultivar and fertilizer combination. In the tuber quality parameters, Bellete had the highest dry matter (23.28%) and specific gravity (1.094 g cm-1), whereas the lowest (17.65% and 1.070 g cm-1) were recorded from local. Partial budget analysis also confirmed that the Bellete cultivar with 166.5 kg N ha^{-1} had the highest MRR (1850), which was the most economically feasible regarding potato yield and quality. Thus, the cultivar Bellete with 166.5 kg N ha^{-1} can be used for potato production in the study area.

Keywords: Cultivar, Fertilizer, Marketable, Production, Tuber yield

Introduction

Potatoes are rich in several nutrients, such as iron, zinc, and vitamin C. According to FAO (2008), potatoes are also a good source of vitamins B_1, B_3 and B_6 and minerals such as potassium, phosphorus and magnesium, and contain folate, pantothenic acid, and riboflavin. It also contains dietary fiber and antioxidants, which may play a part in preventing diseases related to aging. Its nutritional value (balance of proteins to calories, the balance among the more important amino acids in protein, and the level and spread of minerals) makes it next to eggs (Gebremedhin, 2013). In terms of the volume of world crop production, it ranks fourth, following wheat, maize, and rice (FAO, 2000).

The production of potatoes is expanding at a faster rate than other food crops in developing countries, including Ethiopia. In 2014/2015, the area under potato crops has increased to 67,362 ha and its productivity is about 921,832 tons in Ethiopia. Its national productivity improved from 7.7 t ha^{-1} in 2000 to 13.7 t ha−1 in 2014/2015 (FAOSTAT, 2016). However, the yield potential of potatoes has been reported to reach about 100 t ha−1 (FAOSTAT, 2014). Since an estimated 70% of the country's arable land is potentially suitable for potato cultivation, Ethiopia has possibly the highest potential for potato production of any country in Africa. Most of this land is contained in the central highlands, at an altitude ranging from 1,500 to 3,000 meters above sea level and with an annual precipitation of 600 to 1,200 millimeters (Gebremedhin, 2013). A shorter growing period makes it possible for the farmers to use this crop in a system where more than one crop is possible on the same land per season (Mohammed et al., 2016).

The studies on potato so far have been focused on pest aspects (Sileshi and Teriessa, 2001); adaptation to abiotic stresses and seed systems (Hirpa et al., 2010); yield performance, profitability, and nutrient use efficiency (Hailu et al., 2017). Israel et al. (2012) also reported that the application of appropriate fertilizers has a significant influence on potato tuber yield increment of up to 56.36%. In the study area, many farmers who grow potatoes frequently give less focus to cultivars and application levels of nitrogen (N) for their higher yields. The farmers in the study area were using similar rates of nitrogen for different cultivars of potatoes grown on lands of various fertility levels.

Due to its shallow root system, the low fertilizer use efficiency of the crop leads growers to add a lot of fertilizer, which may not be fully used by the crop (Zebarth *et al.*, 2004). Excess N fertilizer can negatively impact the yield and quality of tubers through leaching of N from the rhizosphere, leading to economic waste and the potential for negative environmental impacts. Nitrogen management strategies have been proposed to reduce the risk of NO_3-leaching in potato production, including the use of N efficient cultivars of a crop; split application of N fertilizer; and use of controlled-release fertilizer products or organic fertilizers (Hopkins *et al.,* 2008). Many factors influenced potato yield and yield components, most notably growing conditions such as fertilization and cultivars (Elfnesh et al., 2011).

Nitrogen being one of the most important limiting nutrients for potato production, there were no area-specific research recommendations. The farmers use different amounts of urea that are not economically feasible and environmentally friendly for better productivity of potatoes (Hailu *et al.,* 2017). Thus, the current study was undertaken to identify and select the best performing potato cultivar using the optimum level of N fertilizer for the production suitable for the Wolaita area.

Materials and methods

The study area

The experiment was conducted at the research site of Wolaita Sodo University, Ethiopia, in 2019/2020. The experimental site is located at 60 49 'N, 370 45'E, and has an altitude of 1886 meters above sea level. The area experiences a bimodal type of rainfall, *i.e.,* the shortest rainy season is from March to April, during which time potatoes are mainly grown in the area, and the main rainy season is from June to September. The average annual rainfall is approximately 1580 mm, with annual maximum and minimum temperatures of 23.70 °C and 17.70 °C, respectively (NMA, 2015). The soil of the study area was sandy loam, which was slightly acidic (having a pH value of 5.6) with low organic carbon (3.44 %) and total nitrogen content (0.30%) (Table 1).

Table 1. Soil physicochemical properties of the study site

Soil physicochemical characteristics (0 - 30 cm)	Values
Sand (%)	65
Clay (%)	12
Silt (%)	23
pH $_{water}$ (1:2.5)	5.6
Total N (%)	0.30
Soil texture class	Sandy Loam
OC (%)	3.44
CEC (ppm)	28.32
EC (ppm)	0.55

Where, CEC= Cation Exchange Capacity (ppm), OC = Organic Carbon (%) and EC= Electrical Conductivity (ppm). Source: Areka Agricultural Research Center soil laboratory, 2019.

Treatments as well as experimental design

The experimental treatment consisted of two factors: three potato cultivars, namely Bellete and Gudene, and one local check. The two improved cultivars were obtained from Holleta Agricultural Research Center while the local check was collected from Wolaita Sodo local market. Four rates of nitrogen fertilizer in the form of urea (46% N) (0, 55.5, 111, and 166.5 kg ha-1) were used and arranged in 12 treatment combinations factorial. The treatments were laid out in Randomized Complete Block Design (RCBD) with three replications. The spacing was 60 cm and 30 cm between rows and plants, respectively. The plot size was 3.6 m2 (1.5 m x 2.4 m), with a total of 36 plots. The plots and blocks were separated by a 1 m wide space. The number of rows, tuber seed per row, and total tuber seed per plot were 4, 10, and 40, respectively.

Data collection methods

Phenological and growth

Days to 50% emergence: the number of days until half of the plant population in each plot emerges as shoots above ground.

Days to 50% flowering: the number of days needed for half of the plants in a plot to flower.

Days to physiological maturity: was determined when half of the plant population turned yellow or began to senesce.

Stem number per plant: the average number of main stems produced per hill, taken from eight randomly selected plants from each plot from the central net plot rows at 50% flowering.

Plant height (cm): the length from the base of the ground to the shoot apex, measured at maturity from eight sample plants from each plot.

Leaf number (LN): the average number of leaves on main stems per hill, taken from eight randomly selected plants from each plot.

Yield and yield components

Number of marketable tubers per hill: was taken from selected eight plants of each plot which are free from defects and size (>25 g) were considered as marketable.

The number of unmarketable tubers per hill was taken from selected plants and tubers with cracks, insects or diseases damaged, sun-greened, and under-sized (< 25 g).

Marketable tuber yield (t ha^{-1})**:** the weight of marketable tubers per hill, taken from eight selected plants and converted into tone per hectare.

Total tuber yield (t ha^{-1})**:** the weight of marketable and unmarketable tubers per hill, taken from selected plants per plot and converted to a hectare basis.

Harvest index (HI): determined as the ratio of the dry weight of the tubers (economic yield) to the dry weight of the total biomass (biological yield).

$$\text{HI} = \frac{Tuber\ dry\ matter}{Total\ biological\ dry\ matter} \text{ x } 100$$

Dry matter (DM) (%): five tubers (about 0.5 kg) were chopped into small pieces and mixed thoroughly. Each sample was placed in a paper bag and put in an oven at a temperature of 70^{o}C for 72 hours. Each sample was weighed immediately and recorded as dry weight and dry matter content was determined using the following formula.

$$\text{Dry matter} = \frac{\text{Dry weight}}{\text{Fresh weight}} \text{ X } 100$$

Specific gravity (SG) (g cm^{-3}): tuber specific gravity was calculated according to Wilson and Lindsay (1969).

$$\text{SG} = \frac{\text{Weight in air}}{\text{weight in air} - \text{weight in water}} \text{ x } 100$$

Starch (%): the proportion of starch was calculated from the dry weight as follows:

Starch (%) = 17.546 + 0.891 x (% DM – 24.182)

Where, % DM was determined as indicated above.

PH value of tubers: was measured by using a pH meter (Model PHS-3C) calibrating with standard buffer pH 7.

Partial budget analysis

Marginal rate of return is a marginal net benefit. In this study, 100% was considered as the minimum acceptable rate of return for farmers' recommendations. It is important to note that the acceptable minimum rate of return for farmers' recommendations is 50 to 100% (CIMMYT, 1988).

Gross average tuber yield (kg ha^{-1}) (AvY): an average yield of each treatment converted in a hectare.

Adjusted yield (AjY): Average yield adjusted downward by 10 % to reflect the difference between the experimental yield and yield of farmers.

Gross field benefit (GFB) **(**ETB ha^{-1}): computed by multiplying field gate price (kg ha^{-1}) by adjusted yield thus: GFB = AjY × field gate price for the crop.

Total variable cost (TVC) (ETB ha^{-1}): Cost of fertilizers and other inputs like planting materials preparation used for the experiment. The costs of other inputs and production practices such as labor cost for land preparation, planting, weeding, crop protection, and harvesting was considered to remain the same.

Net benefit (NB) (ETB ha^{-1}): calculated by subtracting the total costs from gross field benefits for each treatment thus: NB = GFB - TVC.

Marginal rate of return (MRR %): calculated by dividing change in net benefit by change in cost.

Statistical analysis

Analysis of variance (ANOVA) was carried out using SAS statistical analysis software version 9 (SAS, 2002). Significant treatment means were separated using the Least Significant Difference (LSD) test at 0.05 probability levels.

Results and discussion

Influence of cultivar and levels of nitrogen fertilizer on the phenology of potato

Days to 50% emergence were significantly ($P < 0.01$) affected by the main effects of cultivar but the effects of nitrogen levels and its interaction were non-significant. Both days to flowering and maturity were significantly affected ($P < 0.01$) by the interaction effect of cultivar and level of N fertilizer (Table 2).

Table 2**.** Mean square values of phenological and growth traits

Sources of variation	DF	Phenological traits			Growth traits		
		DTE	DTF	DTM	SN	PH	LN
Replication	2	0.250^{ns}	1.083^{ns}	2.03^{ns}	0.819^{ns}	21.65^{ns}	1794^{ns}
Cultivar (A)	2	39.250**	190.333**	63.70**	74.995**	3464.65**	38937**
Level of N fertilizer (B)	3	0.028^{ns}	50.769**	342.03**	6.841^{ns}	139.12*	163325**
A X B	6	0.250^{ns}	3.074**	21.58**	2.309^{ns}	34.66^{ns}	2373^{ns}
Error	22	1.0076	0.508	1.30	3.24	31.08	1842

Ns=non-significant; *= significance; and **=highly significance; DTE= Days to 50% emergence; DTF= Days to 50% flowering; DTM= days to physiological maturity; SN= stem number; PH= plant height and LN= leaf number.

The latest emergence was observed by local check (18 days) while the fastest date was observed by cultivar *Gudene* (14 days) (Table 3). It can be seen that the differential emergence dates of the tested cultivars may be due to their inherent character and their ability to sprout faster. It could also be due to the difference in the amount of stored food in the tubers. This finding is in line with that of Nikardi *et al*., (2011) who reported that the potato tuber seed germination varied within cultivars at the same time on plantation.

Table 3. Effect of cultivar and level of nitrogen fertilizer on emergence of potato tubers

Treatments	Days to 50% emergence
Cultivars	
Bellete	15[b]
Gudene	14c
Local check	18 [a]
LSD(0.05)	0.85
Level of N fertilizer (kg ha^{-1})	
0	15.89
55.5	15.89
111	15.89
166.5	16.00
LSD (0.05)	NS
CV (%)	6.31

Means followed by the same letter within a column are not significantly different at 5% level of significance; LSD = Least Significance Difference, CV (%) = Coefficient of Variance.

The current result revealed that increasing N level from 0 to 166.5 kg N ha^{-1} with cultivar *Bellete* extended days to physiological maturity from 91.67 to 108.00, with *Gudene* 92.33 to 109.67 whereas with local 90.00 to 98.00 (Table 4). This could be because N dressing stimulates haulm growth; prolong the growing period and delays crop maturity. Moreover, varieties differ in the genetic potential to respond for nutrient use and hence their interactions are significantly different. This is in agreement with the finding of Tessema et al. (2020) who reported the range of 51 days (Menagesha) to 65.2 days (Bubu) to attain 50% flowering in potato varieties while from 91.0 days (Awash) to 108 days (Marachere) days to reach physiological maturity. Similarly, Fayera (2017) reported that increasing nitrogen rates from zero to 150 kg N ha^{-1} delayed days to 50% maturity from 99.96 to 121.33 at Holeta, Ethiopia. Therefore, a crop with more N will mature late in the season than a crop with less N because late growth is related to excessive haulm development and early tuber growth to less abundant haulm growth (Beukema and Zaag, 1990).

Table 4. Days to 50% flowering and physiological maturity of potato as influenced by cultivar and level of nitrogen fertilizer

Treatment combination		Days to 50% flowering	Days to physiological maturity
Cultivar	Levels of N fertilizer (kg ha^{-1})		
Bellete	0	48.67^{f}	91.67^{gh}
	55.5	48.67^{f}	94.00^{def}
	111	50.33^{e}	95.67^{cd}
	166.5	51.33^{de}	108.00^{a}
Gudene	0	44.00^{i}	92.33^{fg}
	55.5	46.00^{h}	93.67^{ef}
	111	47.33^{g}	96.00^{c}
	166.5	51.00^{de}	109.67^{a}
Local check	0	52.00^{d}	90.00^{h}
	55.5	53.33^{c}	92.33^{fg}
	111	55.67^{b}	94.33^{cde}
	166.5	58.67^{a}	98.00^{b}
CV (%)		1.41	1.18
LSD (0.05)		1.00	1.69

Means followed by the same letter within a column are not significantly different at 5% level of significance, LSD = Least Significance Difference, CV (%) = Coefficient of Variance.

Influence of cultivar and level of nitrogen on growth of potato

Stem number

The stem number of potatoes was significantly ($P < 0.01$) affected by cultivar, but that of N and the interaction effects were non-significant (Table 2). Out of the studied cultivars, *Gudene* produced a large number of stems (9.69); followed by *Bellete* (8.74) whereas the least number (4.97) of stems per hill was produced by the local check (Table 5). From these results, it can be observed that the number of stems depends on the cultivar rather than the rate of fertilization. A potato plant consists of a variable number of stems; the exact number depends upon the size and treatments of the plant's parent tuber. This might be due to the variability in the number of sprouts in the tuber. In line with the current findings, Shenkolla variety produced the maximum stem number per plant (7.3) while the minimum stem number per plant (2.5) was recorded from the variety Menagesha (Sadik et al. 2018). These results are also in agreement with the findings of Tessema et al. (2020) who reported a significant influence of varieties on stem number per hill. They found a maximum of 7.3 and a minimum of 2.5 stem numbers per plant in potato varieties studied.

Plant height

Plant height responded significantly ($P < 0.01$) to the cultivar (Table 2). It was also significantly ($P < 0.05$) influenced by the level of N fertilizer. Out of the studied cultivars, *Gudene* was the highest (79.23 cm) whereas the shortest (46.09 cm) plant height was recorded by the local check (Table 5). From this result, it can be observed that plant height highly depends on the effects of both cultivar and level of N. This may be also due to the apparent effect of N to stimulate vegetative growth and hence encourages the growth of plants, large stem internodes, and leaves. In line with the current finding, Sharma et al. (2014) reported that plant height increased with increasing fertilizer levels of nitrogen. This could be attributed to the enhanced availability of nutrients to the crop for its vegetative growth. Again Sebnie et al. (2021) reported a height increment of 16.14 due to the application of 138 kg N ha−1 over the control in 2017 at Sekota, Ethiopia. Feyera (2017) also found a maximum plant height of (92.66 cm) by the application of 150 kg N ha-1 at Holeta, Ethiopia.

Leaf number

Leaf number of the plant was significantly ($P < 0.01$) influenced by both cultivar and N levels; but not significant ($P > 0.05$) due to the interaction effect (Table 2).

Table 5. Effect of cultivar and level of nitrogen fertilizer on growth components of potato

Treatment	SN/hill	PH (cm)	LN/hill
Cultivar			
Bellete	8.74[a]	69.19[b]	598.69[a]
Gudene	9.69[a]	79.23[a]	593.24[a]
Local check	4.97[b]	46.10[c]	497.42[b]
LSD (0.05)	1.52	4.74	36.34
Level of N fertilizer (kg ha^{-1})			
0	6.74[b]	60.28[c]	415.72[d]
55.5	8.85[a]	67.01[ab]	494.57[c]
111	7.96[ab]	69.03[a]	622.60[b]
166.5	7.65[ab]	63.04[bc]	719.58[a]
LSD(0.05)	1.76	5.45	41.96
CV(%)	23.07	8.6	17.8

Means followed by the same letter within a column are not significantly different at 5 % level of significance; SN= stem number, PH (cm) = plant height, LN= leaf number, LSD = Least Significance Difference, CV (%) = Coefficient of Variance

Out of the studied cultivars, Bellete produced more number (598.69) of leaves whereas the least number (497.42) of leaves per plant was produced by the local check (Table 5). From this result, it can be observed that the number of leaves depends on both cultivar and levels of N fertilizer. The increment of plant height, number of leaves and shoot with the increase of levels of N may be due to the fact that higher N concentration stimulated the assimilation of carbohydrates and proteins, which in turn enhanced cell division and formation of more tissues that resulted in enhanced vegetative growth of the plant and also in the production of stem and axillary branches (Simret, 2010). This result is in line with the findings of Tessema et al. (2020) who reported the maximum and the minimum number of leaves per hill were recorded from the varieties Shenkolla and Menagesha (51.9 cm and 30.5cm), respectively.

Yield and yield components of potato

Number of marketable tubers per hill

The number of marketable tubers per hill was significantly ($P < 0.05$) affected by the interaction effect of cultivar and level of N application (Table 6). Among the studied cultivar and level of N fertilizer treatment combinations, *Bellete* with 166.5 kg N ha-1 produced the highest number (15.67) of marketable tubers per hill followed by *Gudene* with 166.5 kg N ha-1; (15.00), whereas the least (3.33) marketable tubers per hill was produced by the local check without N application (Table 7). From this result, it can be observed that the number of marketable tuber per hill depends on the interaction effects of cultivar and the rate of fertilization. This may probably be since N is an important plant nutrient that has a role in metabolic and physiological functions thereby affecting the yield and yield components of the potato plant. This result is also in agreement with the findings of Assefa (2005) who reported that the increasing application of N from 0 to 150 kg ha-1 increased the marketable tuber number per hill. Furthermore, Israel (2012) found that increasing the application rate of N from 0 – 165 kg/ha increased the total tuber number by 31.7% in Potato.

Table 6. ANOVA for mean square values of yield and yield components

Sources of variation	DF	Nº of marketable tubers	Nº of unmarketable tubers	Marketable yield	Total yield
Replication	2	2.19^{ns}	0.11^{ns}	26.87^{ns}	45.89^{ns}
Cultivar (A)	2	22.03**	32.86**	987.59**	584.90**
Level of N fertilizer (B)	3	145.36**	27.58**	140.350**	136.98**
A X B	6	1.58*	0.97*	68.54**	53.58*
Error	22	0.56	0.35	12.53	15.85

ns = non significance; * = Significance; and ** = highly significance.

Number of unmarketable tubers per hill

The number of unmarketable tubers per hill was also significantly (P < 0.05) affected by the interaction effect of cultivar and levels of N fertilizer (Table 6). Out of the studied cultivar and level of N application, local check without N application produced a higher number (8.33) followed by *Gudene* with 0 kg N ha-1 (7.33); whereas the least number (1.00) of unmarketable tubers per hill was produced by the treatment combination of cultivar *Bellete* with 166.5 kg N ha-1 (Table 7). This may be because potato plant variations in an up-taking of nutrients that have a role in metabolic and physiological functions, thereby affecting the yield and yield components of the potato plant. This result is also in agreement with the findings of Frezgi (2007) who reported that N treatment increased the marketable tuber number per hill rather than that of untreated with N. Similarly, Simret et al. (2010) stated that the marketable tuber number increased when nitrogen supply increased from 0 to 100 kg N ha-1. Also, Israel et al. (2012) found the increase in marketable tuber number per hill with the increasing rate of nitrogen application from 0 to 165 kg N ha-1.

Marketable tuber yield (t ha^{-1})

Marketable tuber yield was significantly (P < 0.01) influenced by the interaction effect of cultivar and level of N (Table 6). Accordingly, *Bellete* cultivar with 166.5 kg N ha-1 produced the highest amount (34.15 t ha-1) of marketable tuber yield followed by *Bellete* with 111 kg N ha-1(31.82 t ha-1) although statistically similar whereas the lowest amount (7.48 t ha-1) was produced by the local check without N application (Table 7). From these results, it can be observed that the marketable tuber yield range of about 26.67 t ha-1 was due to treatment effects and the selection of appropriate cultivar and optimum fertilizer rates. This may probably be since N is an important plant nutrient that has a role in metabolic and physiological functions, it affected the yield and yield components of the potato plant. This result is also in agreement with the findings of Mulubrhan (2004) who reported that N treatment increased the marketable tuber yield over the control. Israel (2012) found a marketable tuber yield of 35 t ha-1 using 165 kg N ha-1. Moreover, the highest marketable yield (45.55 t ha−1) was recorded from 138 kg N ha−1 in combination with 23 kg P2O5 ha−1 at Sekota, Ethiopia (Sebnie et al., 2021).

Total tuber yield (t ha^{-1})

The interaction effect of cultivar and level of N fertilizer significantly ($P < 0.01$) influenced the total tuber yield (Table 6). Hence, the highest yield of total tuber (35.20 t ha^{-1}) was obtained from the treatment combination of 166.5 kg N ha^{-1} with the cultivar *Bellete* followed by *Bellete* with 111 kg N ha^{-1} (34.45); whereas the lowest total tuber yields (13.45 t ha^{-1}) were obtained from the local check without N application (Table 7).

Table 7. Number of marketable and unmarketable tubers per hill and yields of potato as influenced by the interaction effect of cultivar and level of nitrogen fertilizer

Treatments		No of Marketable tubers/hill	No of Unmarketable tubers/hill	Marketable yield (t ha^{-1})	Total yield (t ha^{-1})
Cultivar	Levels of N fertilizer (kg ha^{-1})				
Bellete	0	6.67^{f}	4.00^{cde}	13.67^{c}	17.27^{def}
	55.5	9.00^{e}	3.00^{ef}	30.05^{a}	31.70^{ab}
	111	14.00^{b}	2.00^{fg}	31.82^{a}	34.45^{a}
	166.5	15.67^{a}	1.00^{g}	34.15^{a}	35.20^{a}
Gudene	0	5.67^{f}	7.33^{ab}	19.73^{b}	23.18^{cd}
	55.5	9.00^{e}	5.00^{c}	20.60^{b}	25.11^{bc}
	111	12.00^{c}	4.00^{cde}	22.81^{b}	25.20^{bc}
	166.5	15.00^{ab}	3.33^{de}	22.57^{b}	25.47^{bc}
Local check	0	3.33^{g}	8.33^{a}	7.48^{d}	13.45^{f}
	55.5	8.33^{e}	6.67^{b}	8.80^{cd}	13.68^{ef}
	111	10.33^{d}	4.33^{cd}	10.45^{cd}	13. 80^{ef}
	166.5	12.67^{c}	3.33^{de}	11.64^{cd}	20.24^{cde}
CV (%)		7.37	13.63	18.17	17.00
LSD (0.05)		1.05	0.83	4.96	5.58

Means followed by the same letter within a column are not significantly different at 5 % level of significance; NS=non-significance, LSD = Least Significance Difference, CV (%) = Coefficient of Variance.

This is because N affects yield by affecting the number of tubers produced, the size of the tubers, and the time at which maximum yield is obtained (Wilcox and Hoff, 1970). The increased yield may be also due to the higher number of green leaves, vigorous growth that contributed to better light interception used for assimilation, and tuber growth starting earlier. Furthermore, the current finding is supported by the findings of Maier et al. (1994b) who noted a significant interaction between cultivar and level of N fertilizer on potato tuber yield. Setu and Mitiku (2020) also confirmed that mean marketable and total tuber yield advantage of 51.0 and 47.4 %, respectively by application of 150 kg N ha−1 over the control.

Harvest index and some of potato tuber qualities

Harvest Index

Harvest index was significantly ($P < 0.05$) influenced by cultivar but not by the level of N fertilization (Table 8). Out of the studied cultivars, *Bellete* showed the largest percentage (56.08%) of HI followed by *Gudene* (50.25%) whereas the least HI (49.97%) was observed by the local check (Table 9). This indicated that the consequent prolonged shoot growth and the increased duration of a canopy for light interception may produce a much higher final of tubers. This result is in line with the findings of Beukema and Zaag (1990) who reported that the HI tends to be often a wider variation observed between cultivars. However, the unfertilized plants have a much higher harvest index (Wien, 1997).

Table 8. Anova for mean square values of potato tuber qualities traits

Sources of variation	DF	HI	DM	SG	SC	pH
Replication	2	98.45^{ns}	20.44^{ns}	0.00001^{ns}	16.12^{ns}	0.004^{ns}
Cultivar (A)	2	142.57^{*}	297.285^{**}	0.0021^{**}	24.79^{ns}	0.006^{*}
Level of N fertilizer (B)	3	9.05^{ns}	35.54^{**}	0.00012^{*}	24.69^{ns}	0.067^{ns}
A X B	6	22.77^{ns}	62.23^{ns}	0.00004^{ns}	9.59^{ns}	0.0028^{ns}
Error	22	38.79	220.93	0.00004	14.80	0.0186

ns=non significance; *=significance; and **=highly significance.DM=dry matter; HI=harvest index; SG=specific gravity; and SC=starch content

Dry matter content of tubers

The tuber dry matter content was significantly ($P < 0.01$) influenced by the main effects of cultivar and level of N fertilizer. But the interaction effect was non-significant (Table 8). Out of the studied cultivars, *Bellete* gave numerically the highest dry matter content (23.28%)

followed by *Gudene* (22.44%) whereas the lower dry matter content (17.65 %) was recorded for the local check (Table 9). The variation in tuber dry matter contents may be attributed to cultivars' inherent differences and level of N fertilizer. Different authors also indicated the highest dry matter content with higher levels of fertilizer applications (Israel, 2012; Feyera, 2017). In addition, Desta (2020) reported the highest tuber dry matter content (26.8%) by the application of NPK (110 kg N + 90 kg P2O5 + 69 kg K2O ha-1). Potatoes with a dry matter content of up to 24% are ideal for preparing crisps (Kabira and Berga, 2003).

Specific gravity

The specific gravity of the tubers was significantly ($P < 0.05$) affected by the main effects of cultivar and level of N fertilizer, whereas the interaction effect was non-significant (Table 8). Out of the studied cultivars, *Bellete* produced numerically the largest values (1.094 g cm-3) of specific gravity followed by *Gudene* (1.090 g cm-3); whereas the least values (1.070 g cm-3) were observed by the local check (Table 9). From these results, the tuber-specific gravity was found to be influenced by cultivar and level of N application. This finding is in agreement with the findings of Fitzpatrick et al. (1969) who categorized tuber-specific gravity values as low if less than 1.077; intermediate if between 1.077 and 1.086, and high if more than 1.086. Accordingly, tubers of *Bellete* and *Gudene* are grouped under the high category of specific gravity. It was also in line with the findings of Kabira and Berga (2003) that showed potatoes should have a specific gravity value of more than 1.080 and potato tubers with a specific gravity value of less than 1.070 to be generally unacceptable for processing. In this study, the two improved cultivars (*Bellete* and *Gudene*) had dry matter content of above 20% and a specific gravity of higher than 1.070 indicating that they are suitable for chip making.

Table 9. Effect of cultivar and level of nitrogen fertilizer on harvest index, dry matter, specific gravity and pH values of potato tuber

Treatment	HI (%)	DM (%)	SG (g cm^{-3})	pH
Cultivar				
Bellete	56.08[a]	23.28[a]	1.09[a]	6.19[a]
Gudene	50.25[b]	22.44[b]	1.09[a]	6.11[ab]
Local check	49.97[b]	17.98[c]	1.07[b]	6.05[b]
LSD (0.05)	5.27	0.81	0.01	0.11
Level of N fertilizer (kg ha^{-1})				
0	50.95	21.80[ab]	1.09[a]	6.10
55.5	52.67	21.92[a]	1.09[a]	6.10
111	51.63	20.98[bc]	1.08[ab]	6.11
166.5	53.1	20.24[c]	1.08[b]	6.15
LSD (0.05)	NS	0.94	0.001	NS
CV (%)	11.95	4.53	0.55	2.23

Means followed by the same letter within a column are not significantly different at 5 % level of significance; DM=dry matter; NS=non-significant; SG=specific gravity, LSD (0.05) = Least Significance Difference, CV (%) = Coefficient of Variance

pH value of tubers

The pH value was significantly ($P < 0.05$) influenced only by cultivars rather than fertilization as well as the interaction effects of cultivars and the level of N application (Table 8). From the studied cultivars, *Bellete* scored numerically (6.19) followed by *Gudene* (6.11), whereas local check scored 6.05 (Table 9). From these results, it can be observed that the studied cultivars of potatoes have weak acidic pH values. It may be due to the low reducing sugar contents of the tuber which causes the juice to become weak acid. This finding is in agreement with the findings of Nourian et al. (2002) who reported that the pH value of raw potatoes is usually around 6.0.

Partial budget analysis

Partial budget analysis shows that most of the treatments were at an acceptable rate (MRR > 100%). From these results, the combined treatment of cultivar Bellete with 166.5 kg N ha-1 had the greatest net benefit (239, 719 Birr ha-1) with MRR (1850 %) (Table 10). Thus, it could be recommended that using Bellete cultivar of potato with 166.5 kg N ha-1 will be best among the candidate cultivars in the study area and in other similar cultural practices and agro-ecological zones of the country.

Table 10. Marginal rate of return of for potato tubers as affected by cultivar and rate of N fertilizers

TRT	TVC (ETB ha^{-1})	ΔTVC	NB (ETB ha^{-1})	ΔNB	MRR (%)
T9 (*Local* x 0 N kg ha^{-1})	12200	-	48388	-	-
T10 (*Local* x 55.5 N kg ha^{-1})	13768	1568	57512	9124	582
T11 (*Local* x 111 N kg ha^{-1})	14728	960	69917	12405	1292
T12 (*Local* x 166.5 N kg ha^{-1})	15696	968	78588	8671	896
T5 (*Gudene* x 0 N kg ha^{-1})	21200	5504	138613	60025	1091
T6 (*Gudene* x 55.5 N kg ha^{-1})	22768	1568	144092	5479	349
T7 (*Gudene* x 111 N kg ha^{-1})	23728	960	161033	16941	1765
T2 (*Bellete* x 55.5 N kg ha^{-1})	34968	11240	208437	47404	422
T3 (*Bellete* x 111 N kg ha^{-1})	35928	960	221814	13377	1393
T4 (*Bellete* x 166.5 N kg ha^{-1})	36896	968	239,719	17905	1850

TVC= Total variable cost**,** ΔTVC = change in total variable cost, NB= net benefit, ΔNB= change in net benefit and MRR= marginal rate of return whereas ETB=Ethiopian birr.

Conclusion

The current investigation confirmed that the selection of the best cultivar and optimum level of fertilizer combination is of paramount importance in potato yield and quality. The highest marketable tuber yield and of the best quality was observed by cultivar *Bellete* with 166.5 kg N ha^{-1}. The partial budget analysis also revealed similar findings in that the highest MRR (1850 %) was obtained by treatment combinations of *Bellete* with 166.5 kg N ha^{-1}. Therefore, it can be concluded that producing potato cultivar *Bellete* using 166.5 kg N ha^{-1} in Wolaita area was found to be economically feasible with the highest marketable yield and best processing quality among the tested cultivars.

Conflict of Interest

The authors have no conflict of interest any issues related to this manuscript.

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