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RESEARCH ARTICLE

Response of potato (*Solanum tuberosum* L.) varieties to blended NPSB fertilizer rates on tuber yield and quality parameters in Gummer district, Southern Ethiopia

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Abstract

Potato is an important food security and cash crop in Southern Ethiopia, including Gurage Zone. However, the productivity of the crop in the zone is far below its potential due to an array of factors. For instance, inappropriate selection of varieties and lacking information regarding the actual rate of the newly recommended blended NPSB fertilizer in the potato-producing areas, including Gummer district. Cognizant of this, the present experiment was initiated and conducted in Gummer district under supplementary irrigation, during the 2021 Belg season, with the objective of assessing the response of different potato varieties to blended NPSB fertilizer rates. The experiment was laid out in randomized complete block design (RCBD) with the factorial arrangement and having three replications. There were 12 treatment combinations, comprising three potato varieties (namely; Belete, Gudanie and a local check, Askot) and four blended NPSB fertilizer rates (0, 119, 238 and 357 kg NPSB ha^{-1}). The analysis of variance showed that the two main factors (blended NPSB fertilizer rates and potato varieties) had a statistically significant effect on all tested parameters except the effect of the blended NPSB fertilizer rates on days to 50% emergence. The interaction of the two factors had also showed a statistically significant effect on days to 90% maturity, plant height, main stem number per plant, total tuber number/hill, tuber yield per hill, large-sized tuber yield, marketable and total tuber yields (t ha^{-1}) and tuber dry matter content. Days to 90% maturity were delayed with increased rates of blended NPSB fertilizer for all tested varieties. The highest mean plant height (69.54 cm) and number of main stems per hill (8.38) were obtained at 357 kg ha^{-1} NPSB with Belete variety. The highest marketable tuber yield (34.40 t ha^{-1}), total tuber yield (35.84 t ha^{-1}) and tuber dry matter content of (26.75%) were obtained from belete variety with the application of 238 kg ha^{-1} NPSB fertilizer. The results of the economic analysis indicated that the maximum net benefit (180660.7 Birr ha^{-1}) with a 3405.23% marginal rate of return was obtained from Belete variety with the application of 238 kg NPSB ha^{-1}. Hence, the application of 238 kg ha^{-1} with belete variety can be recommended for optimum potato production with acceptable economic benefit in the study area and similar agroecology. However, since the result is only of one season and location, further research is recommended to be carried out across more seasons and locations.

Keywords: Blended fertilizer, Growth, Potato variety, Quality, Yield components, Yield.

Introduction

Potato is one of the major economically important crops grown in Ethiopia as a source of food and income (Adane *et al.,* 2010), which covered about 85,988.43 ha with about 1,141,871.73 tons of tuber yield and a productivity of 13.28 t ha^{-1} (CSA, 2021). It is mainly grown in the highlands of Ethiopia, at altitudes ranging from 1500 to 2800 meters above sea level (Bezabihi and Mengistu, 2011). It is produced across a wide range of soil conditions, although it is best adapted to fertile, well-drained loamy, sandy loam and clay loam soils, and prefer slightly acidic soils with pH levels ranging from 5.2 to 6.4 (Tesfaye, 2007 and Ermias, 2010).

Ethiopia has many potato varieties provided by many research institutes, including old cultivars (local) that farmers plant. However, for various reasons, locally produced potatoes are low in tuber yield and poor in quality compared to the improved varieties (Tekalign Tsegaw and Hammes, 2005). The distribution of varieties differs among agroecologies as the farmers attributes were most concerned with like drought tolerance, late blight

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resistance, yield potential, marketability, food value, storage quality, adaptation to low soil fertility, days to maturity and suitability for multiple harvesting. Although these new varieties are produced in some areas of the country (Gebremedhin *et al.,* 2013), farmer adoption in most potato production areas is low, resulting in just a small number of them being grown. Hence, most of the farmers are growing old potato varieties (Gebremedhin *et al.,* 2013) associated with lack of improved seed tubers (Semagn *et al.,* 2015). Therefore, it is important to identify adaptable and high-yielding potato varieties/cultivars for the study area.

To cultivate potato, Ethiopian farmers used blanket fertilizer recommendations such as 165 kg urea and 195 kg DAP ha^{-1}, for the past five decades (EIAR, 2007). However, these types of fertilizers deliver only nitrogen and phosphorus, which may not satisfy the nutrient requirements of the crops, including potato in the agricultural soils. According to Hailu (2014), Ethiopian soil lacks most of macro and micronutrients necessary for crop growth and development. Soil inventory data from Ethiopian Soil Information System (EthioSIS) has revealed that, in addition to N and P, most Ethiopian soil, including those in the study area, is deficient in nutrients like S and B (ATA, 2015). To avert the situation, the Ministry of Agriculture of Ethiopia (MoA) recently introduced a newly blended fertilizer (NPSB) which contains N (18.9%), P (37.7%), S (6.95%) and B (0.1%), which substituted DAP as the main source of phosphorous (Ministry of Agriculture and Natural Resource, 2013). However, its optimum application rates for the production of most crops, including potato are not yet known. Therefore, the optimum rates of blended fertilizers necessary for potato production in Ethiopia's southern regions has yet to be determined and more research is needed.

Despite huge demand and production potential, national average productivity, including the study area is lower than the global average productivity (21.77 t ha^{-1}) and African (15.1 t ha^{-1}) (FAOSTAT, 2021). The major problems contributing to lower productivity of the crop are both biotic and abiotic factors, such as the prevalence of disease and insect pests, poor soil fertility management, unavailability and high cost of seed tubers, inadequate storage and marketing facilities (Tekalign and Hammes, 2005; Mesfin *et al.,* 2014). Furthermore, due to limited research results, the farmers in the study area (Gummer district) in particular and the country in general lack information on optimal rate of newly introduced blended fertilizers like NPSB, inappropriate selection of variety and variety-specific recommendations of fertilizer rates. Given these problems, this research was initiated to select high-yielding and adaptable potato varieties with optimum NPSB rate to be applied in the study area.

Materials and Methods

Description of the Study Area

The experiment was conducted on farmer's field in Enjefo *kebele,* in Gummer district, Southern Ethiopia, during the *Belg* season of 2021 entirely using supplemental irrigation. The study site is located at a distance of about 220 km from Addis Ababa in the South West direction and about 62 km from Wolkite, the Administrative Zone. The experimental site is located at 8° 01′ 27.84″N latitude, 38° 01′ 27.84″ E longitude and elevation of 2800 meters above sea level. The average annual rainfall of the study area for ten years was 110 mm with mean annual maximum temperature of 24.69°C and mean minimum temperature of 10.59°C (Figure 1).

Description of Experimental Materials

Two improved potato varieties (Belete and Gudanie) developed and released by Holetta Agricultural Research Center (HARC) and one farmer's local variety (*Askot*) were used for the study. The varieties were selected based on their wide-scale production by the farmers and their production potential in the study area. Fertilizers used for the study were blended fertilizer NPSB (18.9% N, 37.7% P_2O_5, 6.95% S and 0.1% B) and urea (46% N).

Treatments and Experimental Design

The treatments consisted of a factorial combination of four NPSB fertilizer rates (0 (control), 119, 238 and 357 kg ha^{-1}) which was derived on the basis of previous national blanket recommendation of phosphorus (195 kg DAP ha^{-1}) for potato and three potato varieties (Belete, Gudanie and a local check, *Askot*). In addition, the national recommended rate of urea (165 kg ha^{-1}) (EIAR, 2007) was uniformly used for all experimental plots. The experiment was laid down in randomized complete blok design (RCBD) in a factorial arrangement (4×3) with three replications. Each plot had 3.75 m width and 2.4 m length (9 m^2) which accommodated five rows with eight plants per row, a total of 40 plants per plot; with a spacing of 0.75 and 0.3 m between rows and plants, respectively (EIAR, 2007). The distance between the plots and blocks were kept at 1 m and 1.5 m apart, respectively. The outermost one row on both sides of each plot and both ends of each row were considered as border plants, and were not used for data collection to avoid border effects. Thus, the net plot used was 1.8 × 2.25m (4.05 m^2).

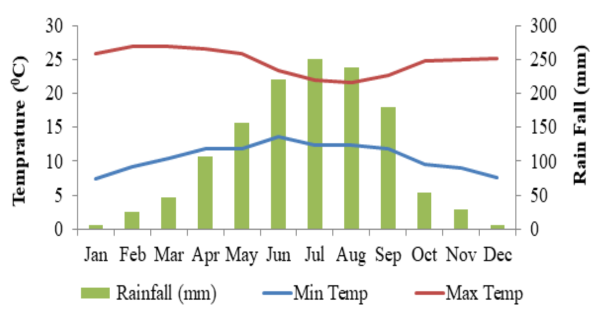

Figure 1: Annual mean rainfall (mm), mean maximum and minimum temperatures (°C) of the experimental site over ten years (2011-2020)
Source: National Meteorological Agency, Ethiopia

Experimental Procedures

The experimental field was ploughed three times with oxen to a fine tilth, and then plots were manually leveled. A field layout was made according to the design, and each treatment was randomly assigned to the experimental units within a block. According to the treatments, all of the blended NPSB fertilizer and a third of urea was applied at planting, and the remaining two-thirds of urea was applied after full emergence and at tuber initiation (at the start of flowering) by side dressing (Tesfaye *et al.,* 2006; MoANR, 2016). All other management practices were done to all experimental plots uniformly per the potato production recommendations.

Data Collection

Soil sampling and analysis procedures

Before planting, representative soil samples were taken from the experimental field at 0 to 30 cm depth using an auger in a zigzag pattern from 20 spot, and a composite soil sample was made. In order to analyze soil physicochemical parameters, the soil sample was air-dried, ground, and sieved with a 2 mm size sieve. For the determination of organic carbon and total N contents, the soil sample was further crushed to pass through a 0.5 mm sieve. The following physicochemical analysis viz, texture, pH, CEC, OC, total N and available P were analyzed at Wolkite Soil Laboratory, and available sulfur and boron at Hawassa Soil Laboratory using standard procedures.

Soil texture was analyzed by determining the soil sample's percentage of sand, silt and clay by following the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH of the soil was determined at 1:2.5 (weight/volume) soils to water dilution ratio using glass electrode attached to digital pH meter (Sahlemedhin and Taye, 2000). Cation exchange capacity (CEC) was determined after saturating the soil with in ammonium acetate (NH_4OAC) and displacing it with in NaOAC (Chapman, 1965). Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934, and soil organic matter was computed by multiplying the percent soil organic carbon by a conversion factor of 1.724. Total nitrogen content of the soil was determined by wet-digestion, distillation and titration procedures of the Kjeldahl method as described by Black (1965). Available phosphorus was determined using the Olsen method (Olsen *et al.,* 1954). Available sulfur was determined by the mono-calcium phosphate extraction method (Hoeft *et al.,* 1973) and available boron was determined using hot water method (Havlin *et al.,* 1999).

Data Collection

Phenological and growth parameters

- *Days to 50% emergence (days)*

Number of days elapsed from planting until 50% of the seed tubers in each plot emerged was counted (Asmamaw, 2007; Elfinesh, 2008).

- *Days to 50% flowering (days)*

The number of days elapsed from planting until 50% of the plants in each plot flowered was counted as described by (Shirie *et al.,* 2009).

- *Days to 90% maturity (days)*

It was recorded by counting the number of days from planting up to the date when 90% of the plants in each plot showed senescence of leaves and haulms as described by Melkamu and Minwyelet (2018).

- *Plant height (cm)*

It was measured from the ground level to the tip of 10 randomly selected plants grown in the net plot area using ruler at the time of flowering (Zelalem *et al.,* 2009) and mean values were computed.

- *Main stem number per hill (count/hill)*

The total number of stems that arose from the ground was counted from 10 randomly selected plants/hills in each plot at time of flowering (Zelalem *et al.,* 2009) and the mean number of stem per hill was computed.

Yield and yield components

- *Total tuber number per hill (number hill^{-1})*

The total number of tubers harvested from 10 randomly selected plants grown in the net plot area was counted and mean tuber number per plant/hill was computed (Zelalem *et al.,* 2009).

- *Tuber yield per hill (kg hill^{-1})*

The tuber yield of ten randomly selected hills/plants in each net plot area was weighted and the mean values were computed.

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

Tubers free of diseases, insect pest damages and above 25 g in weight are considered marketable tubers as indicated by Lung′Aho *et al*., (2007). The weight of such tubers harvested from the net plot area was measured using scaled balance and expressed as ton per hectare.

- *Unmarketable tuber yield (t ha^{-1})*

Tubers harvested from net plot area, which are diseased and insect pest attacked and less than 25 g, misshaped and decayed are considered as unmarketable tuber as indicated by Lung′ Aho *et al*., (2007).

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

Calculated as the sum of the weights of marketable and unmarketable tubers from the net plot area and transformed to ton per hectare (Zelalem *et al.,* 2009).

- *Tuber size distribution (t ha^{-1})*

All tubers from the net plot area were categorized a small (25–38 g), medium (39–75 g) and large (> 75 g) tuber size according to Lung'aho *et al*. (2007).

Quality parameters

Tuber dry matter content (%): Ten tubers representing all size categories were chopped into small sized 1 to 2 cm were cubes mixed thoroughly and subsample each weighing 200 g were taken and placed in the oven at a temperature of 60°C for 15 hours for pre-drying; and further dry at 105 until constant weight attained and expressed in percent method as described by Zelalem *et al*. (2009).

$$\text{Tuber dry matter (\%)} = \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100$$

Specific gravity of tuber (gcm^{-3}): Five kg tubers of all shapes and size were randomly taken from each plot, first weighed in air and then re-weighed suspended in water. Specific gravity was calculated using the following formula (Kleinkop *et al.,* 1987).

$$\text{Specific gravity} = \frac{\text{Weight of tuber in air}}{(\text{Weight of tuber in air - weight in water})}$$

Total starch content (%): The percentages of starch were computed from the specific gravity as follows; Starch (%) =17.546 + 199.07 × (specific gravity-1.0988) (Talburt and Smith, 1959 as cited by Yildrim and Tokusoglu, 2005).

Data Analysis

All the collected data were first checked for fitting the analysis of variance (ANOVA) and examined for normality assumptions. Collected data were subjected to analysis of variance (ANOVA) using SAS (SAS Institute, 2014) version 9.3 software. A general linear model (GLM) procedure of SAS was used. Means were separated using Duncan's multiple range test (DMRT) at 5% probability. Pearson correlation analysis between each parameter studied was carried using SAS software.

Economic Analysis

The partial budget analysis was done for economic analysis as described by CIMMYT (1988). The economic advantages of applied NPSB fertilizer and varieties were carried out using partial budget analysis. In this experiment, cost of variety and NPSB were considered as variable costs. Dominance analysis was carried out by listing the treatments in order of increasing the total variable costs to calculate marginal rate of return, the treatments that have net benefits less or equal to the previous treatment was denominated and discarded for further analysis.

Results and Discussion

Soil Physicochemical Properties of the Experimental Site

The plant available nutrients content on the soil is a prerequisite for crop growth, yields and quality. The physical and chemical properties of soil of the experimental site are indicated in Table 1.

Table 1: Soil physical and chemical characteristics of the study area (before planting)

Soil physical properties	*Result*	*Rating*	*Reference*
Sand (%)	35	-	-
Silt (%)	40	-	-
Clay (%)	25	-	-
Textural Class	Loam	-	(USDA, 1987)
Soil chemical properties			
pH (1: 2.5 H_2O)	5.65	Moderate	(Hazelton and Murphy, 2016)
OM (%)	3.33	Medium	(Hazelton and Murphy, 2016)
OC (%)	1.93	Medium	(Hazelton and Murphy, 2016)
CEC (cmol kg^{-1})	31	High	(Hazelton and Murphy, 2007)
TN (%)	0.15	Medium	(Goronski *et al.,* 2010)
Av. phosphorus (ppm)	7.33	Low	(Hazelton and Murphy, 2016)
Av. sulfur (ppm)	17.87	Low	(Lelago *et al.,* 2016)
Av. Boron (ppm)	0.092	Low	(Benton, 2003)

Where: CEC=Cation Exchange Capacity, OC=Organic Carbon, OM= Organic Matter, TN=Total nitrogen and Av. = Available.

Table 2: Mean squares values of phonological and growth parameters of potato as influenced by varieties and blended NPSB fertilizer at Gummer district, during in 2021 *Belg* season

Parameters	*Replication (d.f.=2)*	*NPSB rates (d.f.=3)*	*Varieties (d.f.=2)*	*NPSB×variety (d.f.=6)*	*Error (d.f=22)*
Days to emergency	0.69	9.44ns	27.69**	5.66ns	4.03
Days to flowering	24.08	341.58**	456.33**	15.22ns	48.36
Days to maturity	24.36	260.47***	259.19***	33.86**	7.76
Plant height	7.36	578.76***	489.42***	53.76*	20.14
Stem number per hill	0.11	10.69***	15.61***	1.13*	0.44

Where: d.f. = degrees of freedom; ns = non-significant,* = significant; ** = highly significant and *** = very highly significant at 5% level of probability.

Phenological and Growth Parameters

The analysis of variance showing the effect of blended NPSB fertilizer and varieties on phonological and growth parameters of potato is indicated in Table 2.

Days to 50% Emergence and Flowering

Days to 50% tubers emergence was highly significantly ($p < 0.01$) influenced by varieties, while the two main factors viz. varieties and blended NPSB fertilizer had highly significant ($p < 0.01$) effect on days to 50% flowering of potato. The interaction of variety and blended NPSB fertilizer had a non-significant effect on days to emergency and flowering of potato (Table 2). Accordingly, local variety (*Askot*) emerged about two weeks earlier (17.17 days) and flowered earlier (62.75 days) as compared to the tested

Table 3: Main effects of varieties and NPSB fertilizer on days to emergence and flowering of potato

Varieties	*Days to 50% emergence*	*Days to 50% flowering*
Belete	19.08[a]	68.92[b]
Gudanie	20.17[a]	75.08[a]
Local	17.17[b]	62.75[c]
Critical range	1.7	5.89
NPSB fertilizer rates (Kg ha^{-1})		
0	18.00[a]	61.11[c]
119	19.33[a]	67.00[bc]
238	19.33[a]	72.78a[b]
357	19.56[a]	74.78[a]
Mean	18.8	68.92
Critical range	1.96	6.80
SE ±	1.16	4.01
CV (%)	10.67	10.09

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and Means followed by the same letter are not significantly different from each other at 5% level of significance according to Duncan's multiple range test.

improved varieties. In contrast, Gudanie variety took longer days to emergency (20.17 days) and flowering (75.08 days) (Table 3); but the two improved varieties were statistically at par in days to emergence which is in agreement with previous study by Getachew (2016) who reported non-significant difference between Gudanie and Belete varieties for days to 50% emergence. The observed variation in terms of days to flowering might be attributed to the genetic variation in completing their vegetative growth and variation in environmental adaptability among the varieties. The current findings are consistent with Bewuketu *et al*. (2015) and Alemayehu *et al*. (2018) who reported; local variety flowered earlier compared to the improved varieties.

Regarding to the main effect of NPSB fertilizer on days to flowering, the earliest days to 50% flowering (61.11 days) was recorded from the control treatment which did not receive any NPSB fertilizer, which is statistically at par with a treatment that received 119 kg NPSB ha^{-1}. In contrast, the longest days required to attain 50% flowering (74.78 days) was recorded from the treatment that received 357 kg NPSB ha^{-1}, statistically similar to a plot that received 238 kg ha^{-1} of NPSB fertilizer (Table 3). Such observed prolonged in days to 50% flowering, as a result of increasing application of fertilizer might be attributed to the positive effect of nitrogen that stimulated growth and prolonged vegetative phase, and delaying the reproductive phase of plants with enhanced the uptake of nutrients including phosphorous (Khan *et al.,* 2009). The current study's findings are consistent with those of other researchers who observed that increasing application rates of blended NPSB fertilizer extended days to 50% flowering of potato (Muluneh, 2018; Gezahegn *et al.,* 2021; Tilaye and Diriba, 2021).

Days to 90% Maturity

Days to maturity of potato were significantly ($p \leq 0.01$) influenced by the main factor of variety, NPSB fertilizer and their interactions (Table 2). The longest days to physiological maturity (120.67 days) were observed from the variety gudanie that received 357 kg NPSB ha^{-1}, which was statistically at par with the application of 238 kg NPSB ha^{-1} on the same variety. In contrary, the earliest days to maturity (95.33 days) were attained from the treatment that did not receive NPSB fertilizer (control) with the local variety (Table 4). The result indicated that plant had different morphological and physiological senescence with the combined effect of variety and inputs including its nutrient utilization of the crops, this could be due to the presence of N, P, S and B plant nutrients with efficient utilizations within genotypes which played an important role in protein synthesis, formulation of some growth hormone among the cultivar that prolong crop on field duration and promote tuber maturation and production. Likewise, Melkamu and Minwyelet (2018) demonstrated without the application of NPS fertilizer on improved varieties of gudanie and belete were late matured compared to variety local.

Plant Height (cm)

The analysis of variance revealed that plant height were significantly ($p \leq 0.05$) influenced by variety, blended NPSB fertilizer rates and their interactions (Table 2). The longer plant height (69.54 cm) was observed in variety belete which received 357 kg ha^{-1} of blended NPSB fertilizer, which was statistically in parity with the application of 238 and 119 kg ha^{-1} NPSB with same variety, and with that of gudanie variety at 357 kg ha^{-1} rate of NPSB fertilizer. While, the shortest plant height (39.89 cm) was recorded from local variety under the control treatment (0 kg^{-1} NPSB) and it was statistically similar with variety belete that did not treat with NPSB fertilizer (Table 5).

Table 4: Interaction effect of blended NPSB fertilizer and varieties on days to 90% maturity

Varieties	*NPSB rate (kg ha^{-1})*			
	0	*119*	*238*	*357*
Local	95.33f	111.67cd	108.33ed	114.67bc
Gudanie	105.00e	114.33bc	113.00cd	120.67a
Belete	114.00c	119.33ba	114.33bc	115.00bc
Mean	112.14			
Critical range	4.72			
SE ±	1.61			
CV (%)	2.48			

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and Means followed by the same letters are not significantly different from each other at 5% level of significance according to Duncan's multiple range test.

Table 5: Interaction effect of blended NPSB fertilizer and varieties on potato plant height and number of main stems per hill

NPSB rate (kg ha^{-1})	*Plant height (cm)*			*Main stem number (hill^{-1})*		
	Variety					
	Local	*Gudanie*	*Belete*	*Local*	*Gudanie*	*Belete*
0	39.89g	48.54ef	43.74gf	3.92e	5.13d	5.25d
119	48.92ef	51.29ef	65.56ab	5.21d	6.98bc	6.03cd
238	52.81ed	59.91bdc	67.86ab	5.44d	7.75ab	8.23ab
357	54.00edc	61.94abc	69.54a	5.15d	7.76ab	8.38a
Mean	55.33			6.245		
Critical range	7.6			1.123		
SE±	2.59			0.38		
CV (%)	8.11			10.62		

Accordingly, the application of 357 kg NPSB ha^{-1} on Belete variety was higher by 42.64% in plant height from the variety local of the unfertilized plot (0 kg NPSB ha^{-1}) (Table 5). This could be due to the genetic variation existed in the potato varieties used in the study, for the availability of balanced nutrients for better growth and development, and the cultivars genetic constituencies varied in meristematic elongation, morphologic variability in agronomic traits in response to the applied fertilizer. Similarly, Melkamu and Minwyelet (2018) observed that improved varieties (Belete and Gudanie) are longer in height compared to local varieties with the same rate of blended NPS fertilizer in different agroecologies.

Number of main stems per hill

The analysis of variance revealed that both main and interaction effect of variety and NPSB fertilizer had a significant ($p \leq 0.05$) effect on main stem number per plant (hill) (Table 2). The highest number of main stems per hill (8.38) was recorded from variety belete with the application rate of 357 kg NPSB ha^{-1}, which in turn was statistically in parity with the same variety at 238 kg ha^{-1} NPSB and that of Gudanie variety which received 238 and 357 kg ha^{-1} NPSB. In contrast, the lowest number of stems per hill (3.92) was recorded in the local variety which did not receive NPSB fertilizer (Table 5). The difference in stem number might be due to genetic difference in response to blended fertilizer. The hereditary variation in nutrient utilization determines the production capability of main stems number and secondary branches. Likewise current study, Melkamu and Minwyelet (2018) demonstrated that local variety produced low number of stems as compared to the improved varieties associated with the genetic makeup of the varieties in responded to blended NPS fertilizer at different locations.

Yield and Yield Components of Potato

The analysis of variance showing the effect of blended NPSB fertilizer rates and varieties on yield and yield components of potato is indicated in Table 6.

Table 6: Mean squares values of yield and yield components of potato as influenced by varieties and blended NPSB fertilizer at Gummer district, during in 2021 Belg season

Parameters	Replication (d.f.=2)	NPSB rate (d.f.=3)	Varieties (d.f.=2)	NPSB× Variety(d.f.=6)	Error (d.f=22)
Number of tuber per hill	0.62	38.42***	18.71***	1.96*	0.66
Tuber yield per hill	0.0017	0.72***	0.810***	0.054**	0.0128
Small tuber size	0.46	6.73***	11.7***	1.16ns	0.62
Medium tuber size	5.15	79.41***	45.28***	3.33ns	1.58
Large tuber size	3.56	168.36***	262.57***	17.61***	2.69
Marketable tuber yield	10.20	384.87***	232.74***	24.027*	7.12
Unmarketable tuber yield	0.155	1.33***	0.415*	0.073ns	0.11
Total tuber yield	12.04	341.48***	215.34***	24.85*	7.46

Where: d.f. = degrees of freedom; ns = non-significant,* = significant; ** = highly significant and *** = very highly significant at 5% level of probability.

Total Tuber Number and Yield per Hill

The analysis of variance showed that the main effect of blended NPSB fertilizer rates and varieties (Table 7); as well as their interactions, significantly ($p \leq 0.05$) affected total tuber number and yield per hill (Table 6). At a rate of 238 kg NPSB ha^{-1}, variety Gudanie produced the highest total tuber number per hill (15.39), and variety Belete produced the highest tuber yield per hill (1.773 kg hill^{-1}). However, the local variety with the unfertilized plot had the lowest tuber number (7.65) and yield per hill (0.682 kg hill^{-1}) (Table 8). This might be the genetic makeup of the crops varied in accumulation of food material accumulation (nutrient uptake), as well as photosynthetic activity response in the rates of blended NPSB fertilizer (Mekides *et al.,* 2020; and Gezahegn *et al.,* 2021). The cultivar had high nutrient uptake of genotypes which leads more fast growth, more foliage and increase in leaf area as well as induced the formation of bigger tubers thereby resulted in higher tuber number and yield per hill.

Tuber Size Distribution

Yield of small and medium-sized tubers

The main effect of variety and NPSB fertilizer had a significant ($p < 0.001$) influence on yield of small and medium sized tubers. However, the interaction effect of the two factors had no significant effect on the yield of small and medium-sized tubers (Table 6). From the main effect of varieties, the highest yield of small sized tubers (5.06 t ha^{-1}) and medium-sized tubers (10.86 t ha^{-1}) obtained from local and Gudanie varieties, respectively, whereas the lowest yield of small-size tubers (3.08 t ha^{-1}) and medium-sized tubers

Table 7: Main effects of variety and blended NPSB fertilizer rates on small sized tuber yield, medium sized tuber yield and unmarketable tuber yield of potato

Varieties	*Small-sized tuber yield (t ha⁻¹)*	*Medium-sized tuber yield (t ha⁻¹)*	*Unmarketable tuber yield (t ha⁻¹)*
Belete	3.08^{c}	9.61^{b}	1.88^{b}
Gudanie	4.02^{b}	10.86^{a}	1.92^{b}
Local	5.06^{a}	7.05^{c}	2.22^{a}
Critical range	0.67	1.07	0.28
NPSB fertilizer rates (Kg ha⁻¹)			
0	4.53^{ab}	5.28^{c}	2.52
119	4.87^{a}	8.53^{b}	2.08
238	3.91^{b}	11.99^{a}	1.66
357	2.9^{c}	10.9^{a}	1.76
Mean	4.05	9.17	2.0042
Critical range	0.77	1.23	0.32
SE ±	0.45	0.73	0.19
CV (%)	19.51	13.71	16.45

(7.05 t ha^{-1}) wwere recorded from Belete and local variety (Table 7). The observed differences in size tuber production could be attributed to genetic variability as well as environmental factors (Kumar *et al.,* 2007; and Alemayehu *et al.,* 2018).

The application of 119 kg NPSB ha^{-1}, produced the highest yield of small size tubers (4.87 tha^{-1}), which was statistically similar to the control treatment (unfertilized plots); whereas the highest yield of medium-sized tubers (11.99 tha^{-1}) were obtained from the application of 238 kg NPSB ha^{-1}. In contrast, the lowest yield of small-sized tubers (2.9 tha^{-1}) and medium sized tubers (5.28 tha^{-1}) were obtained from 357 kg NPSB ha^{-1} and unfertilized plots, respectively (Table 7). This implied the increment of NPSB fertilizer rates, which might positively respond to tubers' tuber initiation process and bulking rates, including tubers' size and shape. In agreement with this finding, Gezahegn et al. (2021) found that when NPSB fertilizer rates increased from 0 to 300 kg ha^{-1}, the proportion of small sized potato tubers reduced by 53.67 to 19.94%, whereas increasing the rates of NPSB fertilizer from 0 to 200 kg ha^{-1} increased the proportion of medium sized tubers by 29.83 to 42.97%.

Yield of large sized tubers

The main effects of blended NPSB fertilizer rates and varieties, as well as their interaction, significantly ($p < 0.001$) influenced yield of large sized tubers (Table 6). The maximum yield of large sized tubers (21.33 tha^{-1}) was obtained from variety Belete treated with 357 kg NPSB ha^{-1}, which was statistically similar with the same variety at 238 kg NPSB ha^{-1}. In contrast, the lowest yield of large-sized tubers (2.02 t ha^{-1}) was obtained from the local variety with unfertilized plots, which was statistically in parity with the same variety which received 119 kg NPSB ha^{-1}, and that of Gudanie variety on unfertilized plots (Table 8). The result shows that varieties respond differently to nutrient requirements inherently, which could be due to genetic variation in tuber size improvement due to adequate nutrient supply could be more luxuriant growth, more foliage and leaf area, and higher photosynthesis supply, which helped in producing bigger tubers, resulting in higher yield of large sized tubers. Furthermore, the significant difference of the tested varieties in yield of large size tubers varied in response to application rates of fertilizer could be attributed to the adaptability and inherent ability of potato varieties in nutrient uptake.

Marketable and total tuber yield

The analysis of variance revealed that both the main effects of blended NPSB fertilizer and varieties, as well their interaction effects had a significant ($p \leq 0.05$) influence on marketable and total tuber yields (Table 6). In interaction effect, application of optimum rate of NPSB (238 kg ha^{-1}) on variety Belete produced maximum marketable and total tuber yields, 34.30 and 35.84 t ha^{-1} respectively, which was statistically similar with the application of 357 kg NPSB ha^{-1} on the same variety. On the other hand, the lowest marketable and total tuber yields were recorded from variety local, 11.48 and 24.40 t ha^{-1}, and which was significantly at par with variety local which received 119 kg ha^{-1} of blended NPSB fertilizer and that of unfertilized plots of Gudanie variety (Table 8).

According to the finding of this study, the application 238 kg/ha^{-1} of NPSB on variety Belete resulted higher marketable and total tuber yields than using a variety local without NPSB fertilizer by about 66.53 and 59.82%, respectively. The difference among the varieties in response

Table 8: Interaction effects of variety and blended NPSB fertilizer on yield and yield components of potato

Treatments		*Variables*				
Varieties	*NPSB (kg ha-1)*	*TNPH*	*TYPH*	*LSTY*	*MTY*	*TTY*
Local	0	7.65^{g}	0.682^{f}	2.02^{e}	11.48^{g}	14.40^{f}
	119	11.51^{ced}	0.759^{ef}	3.17^{e}	15.77^{egf}	17.91^{ef}
	238	11.48^{ced}	0.989^{cd}	8.57^{cb}	21.38^{cd}	23.29^{cd}
	357	10.56^{ef}	0.920^{cde}	8.47^{cb}	21.10^{cd}	23.01^{cd}
Gudanie	0	9.83^{f}	0.801^{def}	3.89^{ed}	13.32^{gf}	15.78^{f}
	119	12.16^{cbd}	1.026^{c}	6.35^{cd}	21.23^{cd}	23.27^{cd}
	238	15.39^{a}	1.443^{b}	9.20^{cb}	27.70^{b}	29.24^{b}
	357	13.65^{b}	1.423^{b}	9.50^{b}	24.21^{cb}	25.84^{cb}
Belete	0	8.07^{g}	0.933^{cde}	7.78^{cb}	16.72^{edf}	18.88^{edf}
	119	10.74^{efd}	1.107^{b}	8.93^{cb}	20.03^{cde}	22.09^{cde}
	238	13.11^{b}	1.773^{a}	19.41^{a}	34.30^{a}	35.84^{a}
	357	12.66^{cb}	1.583^{ab}	21.33^{a}	33.91^{a}	35.65^{a}
Mean		11.40	1.12	9.05	21.76	23.77
Cr.range		1.38	0.19	2.78	4.52	4.63
SE ±		0.47	0.065	0.95	1.54	1.58
CV (%)		7.12	10.1	18.10	12.26	11.49

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; Cr. Range = Critical range; TNPH= Tuber number per hill; TYPH=Tuber yield per hill; LSTY= Large sized tuber yield; MTY=Marketable tuber yield; TTY=Total tuber yield; and Means followed by the same letters are not significantly different from each other at 5% level of significance according to Duncan's multiple range test.

to applied blended NPSB fertilizer, which could be related to their genetic makeup inefficient utilization of inputs including nutrients, which increase above-ground biomass via photosynthesis and net assimilation processes, and re-absorption evidently did not occur from the tubers, could result initiation and bulking rate of tuber with size and weight, and promote increasing tuber yields. The results conformity with the finding of Gezahegn *et al*. (2021) reported that, increased application rates of blended NPSB fertilizer from 0 to 200 kg/ha^{-1}, increased marketable and total tuber yields of variety Bubu by 7.83 and 7.73 tha^{-1}, and variety Gudanie by 11.89 and 10.22 tha^{-1}, respectively.

Unmarketable tuber yield

Analysis of variance showed that unmarketable tuber yield of potato was affected by main effects of both blended NPSB fertilizer rates and varieties significantly ($p \leq 0.05$); while their interaction was not significant (Table 6). Improved varieties of Belete and Gudanie produced lower unmarketable tuber yield by about 18.1 and 15.62%, respectively, compared to the farmer's local variety (Table 7). This might be the cultivar's genetic capacity to improve the tubers' size and weight, adaptability, crop maturity, and the inherent ability of the variety to produce unmarketable tubers per plant. According to Kumar *et al*. (2007) the largest unmarketable tuber yield of a local variety could be associated to the variety character, which determines the unmarketable tuber yield of potato. In agreement with this result, Alemayehu *et al*. (2018) and Sadik *et al*. (2018) reported that local variety produced the highest unmarketable tuber yield than the improved varieties.

Application of 238 and 357 kg ha^{-1} NPSB fertilizer decreased unmarketable tuber yields of potato by 51.81 and 48.18%, respectively, compared to the respective unfertilized plots (Table 7). This indicated that when the rates of fertilizer was increased, the size and weight of tubers increased, possibly because more vegetative growth was initiated, resulting in the production of more photo-assimilate to translocate to the tubers and decrease in the number and yield of unmarketable tubers. This result in consistent with recent findings by Gezahegn *et al*. (2021) and Tilaye and Diriba (2021), who found that by increasing the rates of blended NPSB fertilizer, the unmarketable tuber yield of potato became decreased. Similarly, Desta (2018) reported that increasing the rates of NPS from 0 to 100 kg ha^{-1} significantly decreased the unmarketable tuber yield of potato.

Quality Attributes of potato

The analysis of variance showing the effect of blended NPSB fertilizer rates and varieties on quality parameters of potato is indicated in Table 9.

Dry matter content of Potato tubers

Tuber dry matter content was significantly ($p \leq 0.05$) affected by main effects of varieties and blended NPSB fertilizer rates, and their interactions (Table 9). The highest tuber dry matter content (26.75%) was recorded from variety Belete at 238 kg NPSB ha^{-1}, whereas a local variety which did not received NPSB fertilizer produced lowest tuber dry matter content (18.83%), which was statistically as par with the same variety at 119 kg NPSB ha^{-1} (Table 10). Tuber dry matter content of potato varieties increased with increasing application rates of blended NPSB fertilizer up to 238 kg ha^{-1} which might be the results of the accumulation and partitioning of more assimilates of tubers with their genetic differences and maintaining percent dry matter content of potato tubers with the presence of high level of phosphorous. Similarly, Melkamu and Minwyelet (2018) reported, the highest tuber dry matter contents were obtained from the application of 283.75 kg NPS ha^{-1} on variety Belete (39.13%), Gudanie (37.13%) and local (32.85%), and tubers of Belete variety had the highest dry matter contents followed by Gudanie and local variety across the NPS application rates and locations.

Table 9: Mean squares values of quality parameters as influenced by varieties and blended NPSB fertilizer at Gummer district, during in 2021 Belg season

Parameters	Replication (d.f.=2)	NPSB rates (d.f.=3)	Varieties (d.f.=2)	NPSB × Variety (d.f.=6)	Error (d.f=22)
Tuber Specific gravity	0.000045	0.00036**	0.00066***	0.000044ns	0.000052
Tuber dry matter content	1.74	18.46***	34.69***	4.16*	1.57
Tuber starch content	1.81	14.33**	26.37***	1.76ns	2.066

Where: d.f. = degrees of freedom; ns = non-significant, * = significant; ** = highly significant and *** = very highly significant at 5% level of probability.

Table 10: Interaction effect of NPSB fertilizer and varieties on tuber dry matter content

Varieties	NPSB rate (kg ha^{-1})			
	0	119	238	357
Local	18.83^{d}	19.16^{d}	22.16^{cb}	22.50^{cb}
Gudanie	22.50^{cb}	23.33^{cb}	23.67^{cb}	22.83^{cb}
Belete	21.42^{c}	23.33^{cb}	26.75^{a}	24.25^{b}
Mean	22.56			
Critical range	2.12			
SE±	0.72			
CV (%)	5.55			

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and Means followed by the same letter are not significantly different from each other at 5% level of significance according to Duncan's multiple range test.

Specific gravity and starch contents of potato tubers

The main effects of variety and NPSB fertilizer had a significant ($p<0.05$) effect on specific gravity and total starch contents of potato. However, the interaction effect of blended NPSB fertilizer and varieties did not significantly affect tuber specific gravity and total tuber starch contents of potato (Table 9). From the main effect of varieties, tuber specific gravity and total starch contents of variety Belete was higher than variety Gudanie by about 0.55 and 8.06%, and local by 1.38 and 18.94%, respectively (Table 11). The variation among varieties might be associated with variation in genetic makeup of the varieties to produce solid and starch contents. Similarly, Burton (1966) and Wassu (2016) reported, the genotypic differences of potato had influence on tuber-specific gravity and tuber starch content as well as internal quality traits of potato.

In regarding to blended NPSB fertilizer rates, application of 238 kg NPSB ha^{-1} produced the highest tuber specific gravity (1.088 g/cm^3) and tuber starch content (15.48%), and the lowest tuber specific gravity (1.074 g/cm^3) and tuber starch content (12.56%) were recorded from unfertilized plots (Table 11). The increment of specific gravity and tuber starch content with higher rate of NPSB fertilizer which might be associated with the increased stored assimilates of the tubers, while beyond 238 kg NPSB ha^{-1} did not show a significant effect on specific gravity and tuber starch content. This result agrees with the previous finding of Gezahegn *et al*. (2021) who reported that application of 200 kg ha^{-1} NPSB fertilizer was obtained the highest tuber specific gravity (1.088 g/cm^3), while beyond this rate decreased tuber specific gravity of potato. Similarly, the application of blended type and rates of fertilizers in the rate of 200 and 150 kg ha^{-1} of NPSZn, NPSB and NPS and DAP at 200 kg ha^{-1} produced higher tuber specific gravity as compared to other treatments and control plot.

Table 11: Main effects of variety and blended NPSB fertilizer rates on tuber specific gravity and starch content of potato

Varieties	Tuber specific gravity (g/cm^3)	Total tuber starch content (%)
Belete	1.089^a	15.63^a
Gudanie	1.083^b	14.37^b
Local	1.074^c	12.67^c
Critical range	0.0061	1.22
NPSB fertilizer rates (Kg ha^{-1})		
0	1.074^c	12.56^c
119	1.081^b	14.00^b
238	1.088^a	15.48^a
357	1.085^{ab}	14.84^a
Mean	1.082	14.22
Critical range	0.0071	1.41
SE±	0.0042	0.83
CV (%)	0.67	10.11

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and Means followed by the same letter are not significantly different from each other at 5% level of significance according to Duncan's multiple range test.

Correlation of Growth, Yield and Quality of Potato

The analysis of the correlation between growth, yield parameters and yield are indicated in Table 12. Positively correlated parameters showed that the yield was increased

Table 12: Simple correlation coefficient among different measured traits

	DM	PH	SN	TNPH	TYPH	SsTY	MesTY	LsTY	MTY	UMY	TTY	SPG
DM												
PH	0.63***											
SN	0.66***	0.75***										
TNPH	0.71***	0.64***	0.71***									
TYPH	0.6***	0.79***	0.87***	0.69***								
SsTY	-0.49**	-0.58***	-0.52**	-0.26^{ns}	-0.59***							
MesTY	0.73***	0.62***	0.76***	0.82***	0.78***	-0.47**						
LsTY	0.48**	0.73***	0.73***	0.46**	0.82***	-0.64***	0.6***					
MTY	0.61***	0.72***	0.81***	0.69***	0.88***	-0.52**	0.84***	0.92***				
UMTY	-0.66***	-0.62***	-0.70***	-0.71***	-0.7***	0.48**	-0.67***	-0.52***	-0.63***			
TTY	0.59***	0.71***	0.80***	0.67***	0.87***	-0.51**	0.83***	0.92***	0.99***	-0.59***		
SPG	0.51**	0.61***	0.70***	0.56***	0.69***	-0.55***	0.68***	0.67***	0.71***	-0.47**	0.71***	
TDM	0.66***	0.66***	0.67***	0.52**	0.71***	-0.64***	0.60***	0.67***	0.66***	-0.48**	0.66***	0.69***

Where: DM = Days to maturity; PH = Plant height; SN = Number of main stems per hill; TNPH =Tuber yield per hill; SsTY = Small sized tuber yield; MesTY = Medium sized tuber yield; LsTY = Large sized tuber yield; MTY = Marketable tuber yield; UMTY = Unmarketable tuber yield, TTY= Total tuber yield, SPG = Specific gravity of tuber and TDM = Tuber dry matter content.

Table 13: Partial budget and MRR analysis for NPSB fertilizer rate and varieties of potato

NPSB (kg ha^{-1})	AMY (t ha^{-1})	AJMY (t ha^{-1})	GFB (birr ha^{-1})	TVC (birr ha^{-1})	NB (birr ha^{-1})	MRR (%)
0	11.48	10.33	74376	23733.3	50642.7	-
119	15.77	14.19	102168	25601.6	76566.4	1387.6
238	21.38	19.24	138528	27469.9	111058.1	1846.2
357	21.10	18.99	136728	29338.2	107389.8	D
0	13.32	11.99	86328	34133.3	52194.7	D
119	21.23	19.11	137592	36001.6	101590.4	2643.88
0	16.72	15.05	108360	37866.7	70493.3	D
238	27.70	24.93	179496	37869.9	141626.1	2222
119	20.03	18.03	129816	39735	90081	D
357	24.21	21.79	156888	39738.2	117149.8	8459
238	34.30	30.87	222264	41603.3	180660.7	3405.23
357	33.91	30.52	219744	43471.6	176272.4	D

Where: AMT= Average marketable yield; AJMY= Adjusted marketable yield; GFB= Gross field benefit; TVC= Total variable cost; NB= Net benefit; MRR= Marginal rate of return; D= Dominated treatment; and price of seed tubers of the variety: local variety = 8.90 Eth-Birr kg^{-1}; Gudanie variety =12.80 Eth-Birr kg^{-1}; Belete variety = 14.20 Eth-Birr kg^{-1}; NPSB cost=15.70 Birr kg^{-1}; and price of ware potato at farm gate = 7.20 Birr kg^{-1}.

they as yield related parameters increased while negatively correlated parameters showed that yield increased the parameters decreased as indicated by Zelealem *et al.,* (2009).

Economic Analysis

The result of partial budget analysis showed that the maximum net benefit (180660.7 Birr ha^{-1}) with marginal rate of return (3405.23%) was obtained from variety Belete with 238 kg ha^{-1} of NPSB fertilizer application, whereas the lowest net benefit (1387.6 Birr ha^{-1}) obtained from control (0 kg ha^{-1} NPSB) of variety local (Table 13). The economic analysis of the treatments using a partial budget method showed that net benefit income of tested potato varieties was higher as NPSB fertilizer rates increased to a certain level (238 kg ha^{-1}). In terms of benefit, Birr 130018 (71.96%) of 238 kg NPSB ha^{-1} with variety Belete was found to have a net advantage over the control treatment of variety local.

Conclusions

In the present study, almost all the tested phenological, growth, tuber yield and quality components influenced by that of variety and blended NPSB fertilizer. Likewise, the interaction effect of variety and blended fertilizer influenced a number of traits like days to 90% maturity, plant height, main stem numbers, large-sized tuber yield, average tuber number per hill, tuber yield per hill, marketable tuber yield, total tuber yield and tuber dry matter contents of potato. Moreover, the present study confirmed that increasing the rates of blended NPSB fertilizer from 0 to 357 kg ha^{-1} delayed days to maturity, increased plant height, stem number per plant, and larger-sized tuber yield. However, total tuber number per hill, tuber yield per hill, marketable and total tuber yield, and tuber dry matter contents of the varieties increased with increased NPSB fertilizer level up to 238 kg/ha^{-1} but when NPSB fertilizer increased, more than 238 kg/ha^{-1} these parameters showed a decrease in magnitude.

Generally, the improved varieties used in the present study performed well in all the tested parameters except in phonological parameters of potato, where Belete variety recorded the highest tuber yield with the application of 238 kg NPSB ha^{-1} (35.84 t ha^{-1}), which is increased tuber yield by 47.32 and 59.82% as compared to the control (zero fertilizer) with varieties of the same and local. Application of 238 kg ha^{-1} with Belete variety obtained the highest net benefit (180660.7 Birr ha^{-1}) with a marginal rate of return (3405.23%) which is economically feasible for potato production in the study area.

Recommendations

Based on the results of the present study, it is recommended that NPSB fertilizer at the rate of 238 kg ha^{-1} with Belete variety is economically and agronomically feasible in the study area. However, further study is required under rainfall conditions, across more locations and years/seasons to come up with a more conclusive recommendation for the study area.

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