RESPONSE OF POTATO (*Solanum tuberosum* L.) VARIETIES TO BLENDED NPSB FERTILIZER ON GROWTH, YIELD AND QUALITY PARAMETERS AT GUMMER DISTRICT, SOUTHERN ETHIOPIA

MSc THESIS

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MARCH 2022

Response of Potato (*Solanum tuberosum* L.) Varieties to Blended NPSB Fertilizer on Growth, Yield and Quality Parameters at Gummer District, Southern Ethiopia

A Thesis Submitted to the Department of Horticulture
College of Agriculture and Natural Resource, School of
Graduate Studies, Wolkite University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture

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March 2022

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DEDICATION

So affectionately, I dedicate this thesis to my families for all their enormous and unreserved contributions towards my entire life and academic success.

STATEMENT OF THE AUTHOR

I hereby declare that this thesis is my own work. I have followed all the ethical and technical principles all across the proposal preparation and subsequent experimental work, data collection, data analysis and final write up of the thesis.

The thesis has been submitted in partial fulfillment of the requirements for Master of Science (MSc.) in Horticulture to Wolkite University. It is deposited in the Library of Wolkite University and is made available to all users in compliance to its rules. I also solemnly declare that this thesis has not been submitted to any institution anywhere for the award of any academic degree, diploma or certificate.

Name: Damtew Girma Legese Signature: _____

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BIOGRAPHICAL SKETCH

The author, Damtew Grima Legese, was born on 21 May 1989 in Merhabete district, North Showa Zone, Amhara Regional Staten of Ethiopia. He attended primary education (grade 1-8) at Zeita General Primary School from 1996-2002, and secondary and preparatory education (grade 9-12) at Alem Ketema town from 2003-2006. He then joined Wolkite University, College of Agriculture and Natural Resources in October 2007 and graduated with BSc. degree in Horticulture in June 2009. Subsequently, he was recruited by Wolkite University as a Senior Technical Assistant in the Department of Horticulture, College of Agriculture and Natural Resources, where he served for two years up until he joined the School of Graduate Studies again at Wolkite University in 2012 to pursue his study leading to the Degree of Master Science (MSc.) in Horticulture.

ACKNOWLEDGEMENTS

First and foremost, I would like to sincerely the Almighty God for giving me the endurance and strength to accomplish my study.

I would like to express my heartfelt gratitude to my advisors, Dr. Addisalem Mebratu (major advisor) and Dr. Fresew Belete (co-advisor) for their invaluable guidance and critical review of both the proposal and final thesis.

I would like to thank Wolkite University for granting me the chance to upgrade my academic status as well as covering all the financial expenses for the research work.

I also would like to extend my heartfelt gratitude to the staff of Horticulture Department especially, Dr. Zenebe Woldu, Adane Fentaye and Dagim Demelash for their unreserved assistance over the whole period my research work (both in the field and laboratory) and final write up of the thesis.

Last but not least, I would like to express my sincere gratitude to my beloved parents, i.e. Mr. Girma Legese (my father), Mrs. Asefu Derib (my mother) and all my siblings for their unreserved love and support over the whole period of my life and academic progress.

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
ATP	Adenosine Triphosphate
CIMMYT	Center of International Maize and Wheat Improvement
CIP	International Potato Center
CSA	Central Statistics Agency
CV	Coefficient of Variation
DAP	Di-Ammonium Phosphate
DMRT	Duncan's Multiple Range Test
DNA	Deoxyribo Nucleic Acid
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agricultural Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistics Database
GLM	General Linear Model
HARC	Holleta Agricultural Research Center
m.a.s.l	Meters Above Sea Level
MoA	Ministry of Agriculture
MoANR	Ministry of Agriculture and Natural Resources
MoARD	Ministry of Agriculture and Rural Development
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SNNPR	Southern Nation, Nationality and Peoples' Region

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Response of Potato (*Solanum tuberosum* L.) Varieties to Blended NPSB Fertilizer on Growth, Yield and Quality Parameters at Gummer District, Southern Ethiopia

ABSTRACT

Potato is an important food security and cash crop in Southern Ethiopia including Gurage Zone. However, 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 factorial arrangement and having three replications. There were 12 treatment combinations, which comprised of three potato varieties (namely; Belete, Gudanie and a local check, Askot) and four rates of 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 (69.54cm) 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 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 the acceptable economic benefit in the study area and similar agro-ecology. 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

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is the most important vegetable crop in *Solanaceae* family originated in South America, and was first cultivated in the Andes in the vicinity of Lake Titicaca near the present border of Peru and Bolivia (Haward, 1969; Horton, 1987). It is the fourth most important food crop after wheat, maize and rice (Haan and Rodriguez, 2016), and globally consumed more than three billion peoples (Gebremedhin *et al*., 2016). In addition, it is among the most important food security crop recommended by the Food and Agriculture Organization (FAO) (André *et al*., 2014) because of its ability to provide a high yield with a high quality per unit input with a shorter crop cycle (Mondal, 2003).

Potato is produced in more than 160 countries around the world (Bishwoyog, 2016). It is grown over an area of approximately 16,494,810 hectares, yielding 359,071,403.00 tons of potato tubers with a global productivity of 21.77 t ha^{-1} (FAOSTAT, 2021). According to FAOSTAT (2021), Asia is the leading continent in potato production, followed by Europe, Americas, Africa and Oceania. China and India are world's top potato producers, followed by Russian Federation, USA and Ukraine (FAOSTAT, 2021). In Africa, potato production covered 1,737,174 hectares, yielding 26,229,159 tons with productivity of 15.1t ha^{-1}. Egypt and Algeria are Africa's top potato growers, followed by South Africa, Morocco, Nigeria and Niger (FAOSTAT, 2021).

In Ethiopia, potato is most economically important crop as a source of food and income (Adane *et al*., 2010) coupled with relatively short growing period and wider adaptability (Tewodros, 2014). Among African countries, Ethiopia has suitable climatic and edaphic conditions for potato production, particularly in highland areas that covers about 70% of the arable land of the country (Tekalign, 2006). Potato is the second most important root and tuber crops in area coverage next to taro/'godere' and third in volume of production after taro/'godere' and sweet potatoes (CSA, 2021). In Ethiopia 1,141,871.73 tons of potato is produced within the area coverage of 85,988.43 hectares of land with a productivity of 13.28 t ha^{-1} (CSA, 2021). In Southern Nations, Nationalities and Peoples (SNNP) region about 13,440.14 hectare of land is under potato production with the total yield of 222,477.7 tons and a productivity of 16.55 t ha^{-1} (CSA, 2021).

Despite huge demand and production potential, national average potato productivity is lower than the global average productivity (21.77 t ha^{-1}) and other African countries such as South Africa (37.33 t ha^{-1}), Algeria (31.17 t ha^{-1}) and Egypt (29.2 t ha^{-1}) (FAOSTAT, 2021). The major problems contributing to lower the productivity of the crop are both biotic and abiotic factors, such as inappropriate selection of variety, lacking information on the optimal rate and types of newly introduced blended fertilizers, 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).

Ethiopia has a lot of potato varieties, which is provided by many research institutes, including old cultivars (local) that farmer's plant. However, due to various reasons, locally produced potatoes are low in tuber yield and poor in quality as compared to the improved varieties (Tekalign Tsegaw and Hammes, 2005). The distribution of varieties differ among agro-ecologies as the farmers attributes were most concerned with like drought tolerance, late blight 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 of 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 rates of application for the production of most of the 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.

Gurage zone is potential area for the production of horticultural crop including potato. The production and productivity of potato in Gummer district is low compared to the yielding capacity of the varieties that are used by the farmers. According to the annual report of Gummer District Agricultural Development Office (2021) (Unpublished), the productivity of potato at farmer's level is about 20.83 t ha^{-1} which is lower than the expected yield potential of the improved varieties (Tesfaye *et al*., 2012). Due to limited research results, the farmers in the study area (Gummer district) in particular and in the country are lacking information on the optimal rate of newly introduced blended fertilizers including NPSB, inappropriate selection of variety and variety specific recommendation of fertilizer rates. In view of these problems this research was initiated to selecting high yielding and adaptable potato varieties with optimum NPSB rate to be applied in the study area.

1.1. Objectives of the Study

1.1.1. General objective

To evaluate response of potato varieties to blended NPSB fertilizer rates on growth, yield and quality parameters at Gummer district, Southern Ethiopia.

1.1.2. Specific objectives

- To determine the optimum rate of blended NPSB fertilizer for growth, yield and yield components, and quality attributes in Gummer district.
- To identify the best performing potato varieties in response to NPSB application.
- To determine economically feasible NPSB fertilizer rate for potato production in the study area.

2. LITERATURE REVIEW

2.1. Origin and Description of Potato

Solanum tuberosum L. is the scientific name for the potato crops, which originated in the Andean mountains of South America and was introduced to Europe in the 17th century. It is a member of the *Solanaceae* family and shares the genus *Solanum* with over 1,000 other plants, including tomato and eggplant (Hawkes and Vander, 1992). *Solanum tuberosum* is divided into two subspecies; the andigena, which is adapted to short day conditions and is mainly grown in the Andes, and *tuberosum* which currently cultivated around the world. This subspecies is believed to descend from andigena potatoes that later adapted to longer day conditions (Vander, 1992).

Potato is a dicotyledonous herbaceous annual plant that grows up to 100 cm (40 inches) tall and produces tubers, which are botanically thickened stems (Spooner, 2010). All of the characteristics of normal stems may be found in potato tubers, including dormant buds (eyes), rudimentary leaves (eye brow scars lining the eyes), and lenticels (surface pores). On the stem, the leaves are spirally arranged. In most cases, leaves are compound, with a midrib rachis and multiple leaflets (Decoteau, 2005). Several pairs of lateral primary leaflets, as well as a terminal leaflet, may be carried by each rachis. Flowers are perfect and produce berries. The ovary develops into a fruit (berry) that contains multiple seeds after fertilization. Although most cultivars yield spherical fruits, certain cultivars generate conical fruits that are green in color. Planting a potato tuber with one or more eyes resulted in the buds sprouting and producing well developed plants. The developing sprout creates adventitious roots, which make up the root system, before the plant emerges. The underground portion of the stems also develops stolon's (rhizomes), which bear tubers at their tips (Anonymous, 2013).

2.2. Economic and Nutritional Value of Potato

Potato can plays an important role in improving food security and income of smallholder potato growers in Ethiopia. As a food crop, potato has a high potential to supply a cheap and quality food within a relatively short period. Potatoes are the perfect food and one of the few that can actually sustain life on its own. It is a well-balanced major plant food with a good ratio between proteins and calories, and has substantial amounts of vitamins,

especially vitamin C, minerals, and trace elements. Moreover, it has the correct balance of protein calories and total calories. It is considered as one of the cheapest sources of energy and the production of protein per unit land is the highest among the four major food crops (rice, maize, wheat and potato) (CIP, 1990).

In Ethiopia, potato has huge potential to improve food security, income, human nutrition, and its potential is increasingly being realized and explored by farmers, private investors, and policy makers. While, national average yields are still far below attainable yield, ample opportunities exist to unleash this crop's potential for increased food security and income generation (Teklemariam, 2014). The Ethiopian government considered as a strategic crop aiming at enhancing food security and economic benefits. As population grows rapidly, increased productivity of potato can improve the livelihood of smallholder potato farmers and is required to meet growing demand (Gildemacher *et al*., 2009). The potato subsector is potentially a great importance for proper growth since it is the best option for many households to generate income in Ethiopia. Potato production could fill the gap in food supply during the hungry months of July to August before the grain crops are being harvested (CSA, 2002).

2.3. Agro-Ecological Requirements of potato in Ethiopia

Due to its geographical and topographical characteristics, Ethiopia has a wide range of climates, from humid to semi-arid; the country has several climate zones (Endalkachew and Ajanaw, 2020). Potatoes are a cool season vegetable with some frost tolerance and have a wide range of climatic adaptation. Its production is more successful when the temperature is between 15 and 25 ^{0}C. Temperatures between 15-20 ^{0}C are ideal for tuber formation, whereas high day temperatures of 20-25 ^{0}C are ideal for vegetative growth. When the temperature rises above 30 ^{0}C, tuber development ceases completely (FAO, 2006). Throughout its growing phase, the potato requires more than 600 mm of water for optimal yield production (FAO, 2014). In Ethiopian conditions, the best growing altitude for potato is between 1800 and 2500 m.a.s.l (Bezabih and Mengistu, 2011), which may be grown both under irrigation and rain.

Potato can be grown in all types of soil except saline (alkaline) and heavy water-logged clay soil. For crop production, sandy loamy soils with high organic matter concentration are preferred. A well-drained loamy or sandy loam, largely free of stones, is required for

optimal potato yield. Potatoes are fairly sensitive to salinity in the soil. Potato yields fell as soil salinity increased (FAO, 2013). Potatoes prefer slightly acidic soils with pH levels ranging from 5.2 to 6.4 (Tesfaye, 2007). In general, well-drained, fertile loamy sand and sandy loam soils with high organic matter content and strong water holding capacity are ideal for potato production (Tesfaye, 2007; Ermias, 2010).

2.4. Trend, Potential and Constraints of Potato Production in Ethiopia

Potato was first introduced to Ethiopia in 1858 by a German botanist, Schimper (Pankrust, 1964) and it is rapidly becoming a popular which occupies relatively largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops (Yigzaw *et al*., 2008). Currently, potato is an important food and cash crop for Ethiopian farmers; hence it is grown in various parts of the country for local consumption and regional export (MoARD, 2005).

Potato production has increased considerably through the twentieth century in Ethiopia. In 1975, the area of cultivation was estimated to 30,000 hectares with an average productivity of about 5 t ha^{-1} (Gebremedhin Woldegiorgis *et al.,* 2001). According to the authors, the area allocated to potato in Ethiopia increased from 50,000 hectares by the mid of 1980's to 160,000 hectares in the early 2001's. Currently, the annual production of potato in *Meher* season is around 1,141,871.725 tons from 85,988.43 hectares of land with the productivity of 13.28 t ha^{-1} (CSA, 2021). An upward trend in potato production might be partly due to the continuing increase in population and subsequent decline in the average farm holdings which forced the implementation of improved technologies for the production of potato.

The major potato producing regions of Ethiopia are Oromia, Amhara and Southern Nations, Nationalities and Peoples (SNNP) in the order of production levels (CSA, 2019). About 85,988.43ha of land is under potato cultivations in Ethiopia where Oromia Region is the leading followed by Amhara and SNNPR with production of 502,791.90; 395,429.50 and 222,477.70 tons, respectively. Regional distribution of potato depicted that Oromia, Amhara and SNNP constitute 44.03, 34.63 and 19.28, respectively of the national potato production (CSA, 2021).

Potato cultivation is possible due to the country's diversified agro-climatic conditions, which cover about 70% of the arable land of country's (Tekalign, 2006). Potatoes are

cultivated in rain feed and irrigation systems by both small scale farmers and commercial producers. However, the production and productivity of potato in Ethiopia in general and in SNNP region in particular is very low compared to other countries and the potentials of the country. This low production and productivity of potato is attributed to many factors including inappropriate agronomic practices, prevalence of disease and insect pests, poor soil fertility management, lack of well adapted and high yielding cultivars, unavailability and high cost of seed tubers, inadequate storage and marketing facilities (Tekalign and Hammes, 2005; Mesfin *et al*., 2014).

2.5. The Importance of Blended Fertilizer for Crop Production

Blended fertilizer is the mechanical mixture of two or more granular fertilizer materials which may contained nitrogen (N), phosphorus (P), sulfur (S) and other essential plant nutrients (Beaton, 1997). Application of balanced fertilizers is the basis to produce more crop output from existing land under cultivation (Amalfitano *et al*., 2017; Caruso *et al*., 2019). Previous fertilizer research in Ethiopia has mostly concentrated on nitrogen (N) and phosphorus (P) fertilizer sources under varied soil types and climatic conditions, with very little work on other key macro and micronutrients (K, S, Fe, Zn, B, etc).

Understanding the plant nutrient requirement of a specific area is critical to increasing crop yield and productivity on a long term basis. However, increasing crop yields only through N and P application can deplete other nutrients (FAO, 2000). Fertilizers are an effective exogenous source of plant nutrients (Akram *et al*., 2007), since plant development and crop production require a sufficient and balanced supply of nutrients to improve productivity by maximizing plant nutrient uptake. According to several researches, chemical fertilizers are the most important nutrient sources for increasing crop productivity (Akram *et al*., 2007). This indicates that the actual amount of fertilizer to apply depends on soil fertility, crop variety and the variety's fertilizer efficiency. In addition to N and P, recent soil inventory data from Ethiopian Soil Information System (EthioSIS) revealed other nutrients including S, B, and Zn are deficient in most Ethiopian soils, including the study area (ATA, 2013). Therefore, the Agricultural Transformation Agency was recommended to use different blended fertilizers including NPSB fertilizer in all parts of the country, including the SNNP region.

2.6. Role of Nitrogen, Phosphorus, Sulfur and Boron on potato production

2.6.1. Role of Nitrogen on Potato Production

Nitrogen is one of the most yield limiting nutrients for crop production in the world and it also applied in the largest quantity for most annual crops to increase yield both in quantity and quality (Huber and Thompson, 2007). Efficient use nitrogen is important for the economic sustainability of cropping systems. In a temperate climate, usually 50% of N applied is effectively used by plants, while a considerable part is lost by leaching and contaminates ground and surface waters (Fageria and Baligar, 2005).

Higher nitrogen levels are linked to greater foliage, increased photosynthetic activity, and tuber translocation (Kumar *et al*., 2007). However, an excess of this nutrient in relation to other nutrients, such as P, K, and S leads to excessive stolon and leaf growth, delayed leaf maturation, tuber differentiation, extended tuber bulking period, and ultimately reduced yield and tuber dry matter (Goffart *et al*., 2008). Whereas a lack of nitrogen inhibits the growth of all plant organs, roots, stems, leaves, and flowers, resulting in reduced plant growth, yellowing, and low fruit and seed harvests (Barker and Bryson, 2007). Shortage of N also restricts tuber size due to reduced leaf area and early defoliation (Goffart *et al*., 2008).

2.6.2. Role of Phosphorus on Potato Production

Phosphorus is one of the most essential mobile macronutrients that have an impact on root growth, plant vigor, flowering and plant production. It is important especially during the reproductive stage of plants (Brady, 2008). Phosphorous is an important component of energy transfer chemicals (ATP), DNA molecules, the genetic information system, cell membranes, and phospho-proteins (Bsawas and Mukherge, 1993).

Phosphorus plays significant role in physiological and biochemical reactions such as photosynthesis, conversion of sugar into starch (Taheri *et al*., 2011). The increase in tuber dry matter content in response to increasing the rate of phosphorous application signify that it is an important nutrient for enhancing production of photo-assimilate and starch storage in tubers. This suggestion is consistent with that of Kumar *et al*. (2013) who stated that P increases photosynthesis, and indicated that translocation of photosynthesis from

source to sink has occurred up to maturity as a result of increased nutrient absorption (Biruk, 2014).

Phosphorus plays an important role in plant nutrition, especially in the early stages of crop development (Jenkins *et al*., 1999). Potato respond differently depending upon soil phosphorous contents coupled with soil pH (Sanderson *et al*., 2003). Potato yield, number of tubers and size of tubers are greatly affected by phosphorus fertilization. Tuber set also increased with application of phosphorus (Freeman *et al*., 1998). Moreover, phosphorus application significantly increased plant height, marketable tuber yield and marketable tuber number (Zelalem *et al*., 2009).

2.6.3. Role of Sulfur on Potato Production

Sulphur (S) is a vital nutrient for life and essential for plant growth due to synthesis of proteins, vitamins containing amino acids and associated with nitrogen metabolism for chlorophyll formation (Zhao *et al*., 1999) and it accumulates 0.2 to 0.5% in plant tissue on dry matter basis (Kumar and Singh, 1992). The increase in growth and yield of potato with application of sulfur can be explained with increased metabolic activities, photosynthesis, assimilation and bulking rate (Sharma, 2015). On the other hand, the decrease in tuber dry matter, starch and essential amino acids particular cystine and leucine were observed with sulfur deficiency (Eppendorfer and Eggum, 1994). Sulfur deficiency may also result poor utilization of nitrogen, phosphorus, potash and a significant reduction of catalase activities at all age of plants (Nasereen *et al*., 2003). Moreover, sulfur has direct effect on soil properties as it may reduce soil pH which may improve the availability of micro elements such as Fe, Zn, Mn and Cu (Prakash *et al*., 1997; Singh *et al*., 1995; Tantawy *et al*., 2009).

2.6.4. Role of Boron on Potato Production

Boron (B) is a micronutrient that is required for optimal plant growth and development. It is involved in many plant processes such as cell wall synthesis, sugar transport, cell division, cell development, auxin metabolism, good pollination and fruit set, seed development, synthesis of amino acids and proteins, nodule formation in legumes and regulation of carbohydrate metabolism. Boron deficiencies occur over a much wide range of soils and crops than deficiencies are found most often in light soils, low organic matter contents and high soil pH levels (Mengel, 1978).

Availability of boron in soil is affected considerably by soil pH. Most boron compounds are soluble at low pH, however if rainfall is considerable, B is lost down the profile via leaching in sandy soils with low pH. It is usually found in organic matter in the surface soil, and when the B concentration declines in the profile, a bushy plant with droopy leaves develops (Muthanna *et al*., 2017). Boron fertilization increased the number of tubers as well as the production of potatoes (Sarkar *et al*., 2018). Inorganic fertilizers, as well as micronutrients, are considered vital for producing high tuber yields. Potato plants require a balanced dose of NPK as well as enough amounts of micronutrients and macronutrients such as boron, sulphur, zinc, and manganese to increase productivity (Singh, 2018).

2.7. Varietal Differences in Potato Growth and Yield Parameters

Potato varieties differ in terms of growth, development, and overall yield performance, as well as the shape, size, and weight of their tubers. According to many researches, there is a significant difference in days to emergence among potato cultivars (Mondal *et al*., 2007; Samih *et al*., 2011; Addisu *et al*., 2013; Dash *et al*., 2018). These variations is probably because of the varieties inherent characteristics like dormancy of tubers also as sprouting, fertilizer rate and storage conditions in relation to environmental conditions (Abubaker *et al*., 2011).

Similarly, potato varieties differ in plant height where the improved potato varieties including Gudanie and Belete are relatively longer than the local variety (Bewuketu *et al*., 2015; Arega *et al*., 2017; Seifu and Betewulign, 2017; Alemayehu *et al*., 2018). Furthermore, according to Tibebu *et al*. (2016), Gudanie variety was significantly longer in height compared to Guasa, Jalenie and Degemegn varieties. According to Alemayehu *et al*. (2018) the genetic differences among varieties influence the number of main stems as well as sprouts or eyes on the tubers. Consistently, Sadik *et al*. (2018) reported that variety significantly influenced stem number as Gudanie variety produced maximum stem number per hill compared to Jalenie and local varieties due to a greater number of sprouts observed in Gudanie variety at planting. The difference in stem number among the varieties was explained by the genetic variability and adaptation history of the varieties (Seifu and Betewulign, 2017).

Different potato varieties had different potential of yield components and yield across more locations (Berhanu and Tewodros, 2016; Habtamu *et al*., 2016). Various researchers

reported that varieties had a significant difference on total tubers yield where improved varieties generally produced maximum total tubers yield than local varieties (Tekalign and Hammes, 2005; Helen *et al*., 2014; Alemayehu *et al*., 2018; Dash *et al*., 2018; Sadik *et al*., 2018; and Solomon *et al*., 2019). The differences in marketable, unmarketable and total tuber yields are generally related to the differences in genetic makeup and tuber sizes of the potato varieties (Seifu and Betewulign, 2017).

2.8. Potato Growth and Yield Response to Blended NPSB Fertilizer

Growth and tuber yield of potato is influenced by with types and rates of applied fertilizer which observed by the findings of different researchers. According to Gezahegn *et al*. (2021); Tilaye and Diriba (2021) delayed flowering of potato and the observed trend of delayed maturity towards the application of higher rates of NPSB fertilizer might be due to sufficient supply of nutrient that promotes vegetative growth and delayed reproductive stage of crops. Furthermore, higher phosphorus application extended days to flowering of potato (Desta, 2018), and application of nitrogen fertilizer at higher rates enhanced vegetative growth by helping the plant to absorb sunlight and produce carbohydrates, but delayed the production of reproductive part and thereby maturity (Tantowijoyo *et al*., 2006).

According to the finding of Gezahegn *et al*. (2021), increasing the rate of blended NPSB fertilizer increased plant height and main stem number per hill linearly. With fertilizer treatment rates ranging from 0 to 350 kg NPSB ha^{-1}, plant height and main stems number per hill increased by 18.58 % and 100%, respectively (Gezahegn *et al*., 2021), and also the application rates of blended NPSB fertilizer increased from 0 to 350 kg ha^{-1}, number of main stems increased from 4.99 to 6.48 per hill (Getachew, 2016). These could be attributed to increased nitrogen and boron availability in the soil for uptake by plant roots, which could have resulted in higher cellular division and elongation, resulting in increased vegetative growth (Gezahegn *et al*., 2021).

Tuber number per hill and average tuber weight of potato increased with increasing rates of blended NPSB fertilizer from zero to 200 and 0 to 300 kg ha^{-1} for Gudanie and Bubu of potato varieties, respectively (Gezahegn *et al*., 2021). These might be due to more fast growth, more foliage and increase in leaf area due to a higher supply of phosphorous containing fertilizer which may have induced the formation of bigger tubers thereby

resulting in higher average tuber weight. According to the findings of Gezahegn *et al*. (2021) and (Getachew, 2016) the importance of NPSB application to maximize the total tuber number per hill should be kept at a moderate rather than at high rates.

According to Tilaye and Diriba (2021) findings increased rates of blended fertilizers (NPS, NPSB and NPSZn) as well as DAP increased marketable tuber yield and decreased unmarketable tuber yield. This increment of marketable yield in the response to increasing rate and type of blended NPS, NPSB and NPSZn fertilizers indicated that the importance of blended fertilizers for growth and productivity of potato, while decreased unmarketable tuber yield due the size of tuber became increased with increasing fertilizer rates with the role initiation of more vegetative growth that resulted production of more photo-assimilate. The increment of total tuber number and average tuber weight of potato in response to the increased supply of blended fertilizer types and rates might be due to more growth, more foliage and increased leaf area and higher supply of phosphorous containing fertilizer, which may have induced formation of total tuber number and bigger tubers thereby leading to higher marketable tuber per hill. Similarly, Birtukan, (2016) reported that, interaction of highest level of nitrogen and phosphorus increased total tuber number of potato.

2.9. Effect of Varieties and Blended NPSB Fertilizer on Potato Growth and Yield Components

Growth, yield components and tuber quality of potato varieties is increase with increasing the rates of different blended fertilizers, where increases in days to flowering, days to maturity, plant height, leaf area index, marketable tuber number, marketable tuber yield, total tuber yield, tuber dry mater, and specific gravity of tuber with increased application rates of different blended fertilizers such as NPS and NPSZnB fertilizer including NPSB, (Mekides *et al*., 2020; and Bewket, 2020).

Tuber yield of potato is also affected by blended fertilizer (NPS, NPSZnB) application rate and variety (Melkamu and Minwyelet, 2018; and Bewket, 2020), that might be related to their genetic makeup in the efficient utilization of inputs like nutrients, which is one of the four major categories of the factors (soil, climatic, genetic and management practices). The rates of nitrogen was increased from 100 to 150 kg N ha^{-1}, the marketable tuber yields of Gudanie, Jalenie and Zengena significantly increased (Fikre, 2012). According to the finding of Gezahegn *et al*. (2021) report, total tuber yields of Gudanie and Bubu varieties

where increased in response to the increasing application rates of NPSB fertilizers as compared to their respective unfertilized plots, which might be the role of fertilizers in enhancing photosynthetic activity and translocation of photosynthetic product to the root, which could have helped in the initiation of more stolen on potatoes varieties (Karenlampi *et al*., 2009). Furthermore, all potato varieties have a positive response for tuber yields with increasing levels of blended (NPS, NPSZnB) fertilizer rates at different location (Mekides, 2016; Minwyelet, 2017; and Bewket, 2020).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted in Gummer District at Enjefo *kebele,* Administrative Zone of Gurage in Southern Nations, Nationalities and Peoples Region (SNNPR) during the *Belg* season of 2021 entirely using supplemental irrigation on farmer`s field. The study site is located about 220 km from the capital city, Addis Ababa 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. Major crops grown in the study area include Barley (*Hordeum vulgare*), Faba bean (*Phaseolus vulgaris*), Field pea (*Pisum sativum*), Wheat (*Triticum aestivum*), Enset (*Ensete ventricosum*) and Potato (*Solanum tuberosum* L.) (Gummer Agricultural Development Office Report, 2021).

According to the weather record from Southern Nation, Nationality and Peoples' Regional State Meteorological Agency and Emdibir sub-station, the mean annual rainfall; annual mean minimum and maximum temperatures of the study area based on the last 10 years (2011-2020) records were 110 mm; and 10.59 ^{0}C and 24.69 ^{0}C, respectively.

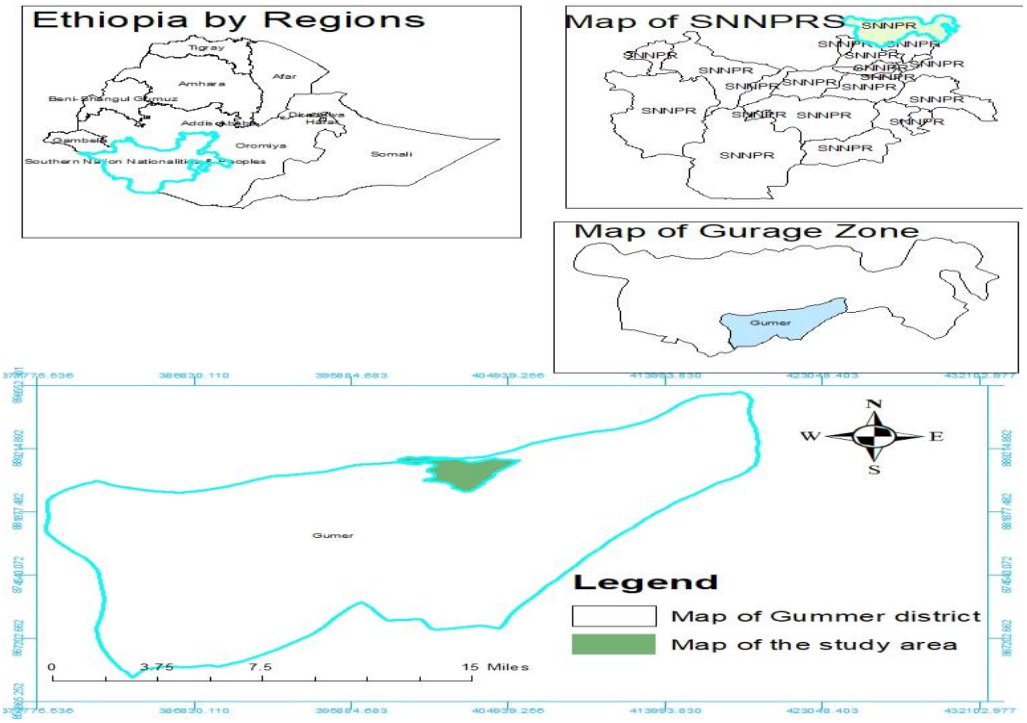
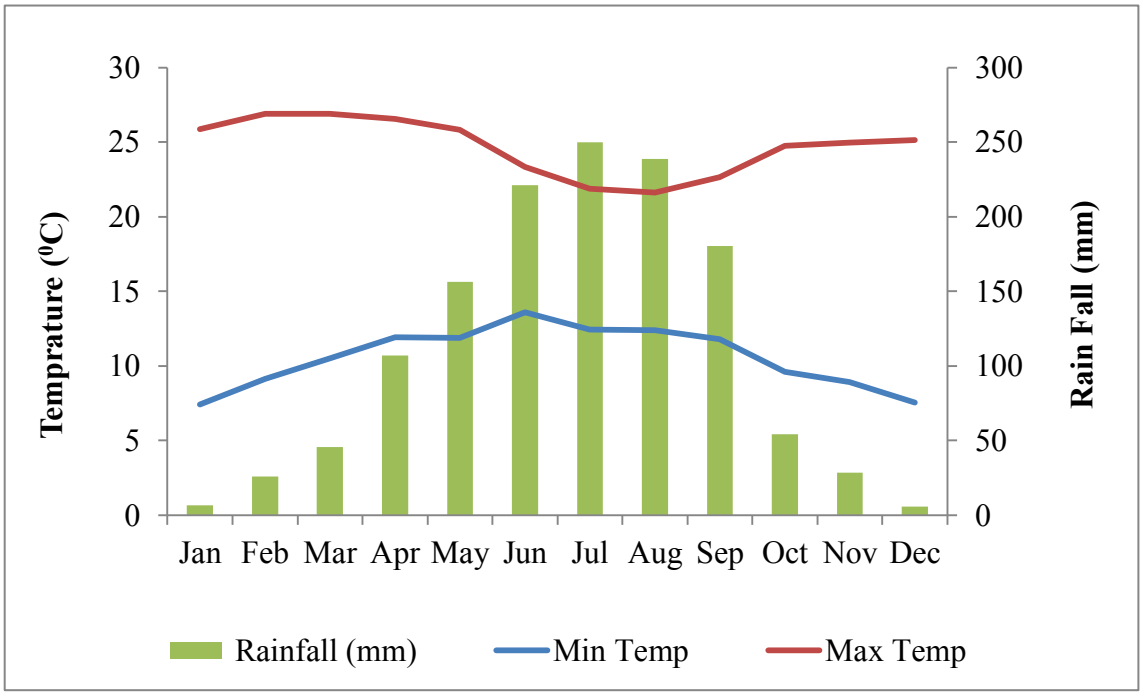


Figure 1: Map of the study area

Figure 2: Mean monthly rainfall; and maximum and minimum temperature of the study area



Source: Southern Nation, Nationality and Peoples' Regional State Meteorological Services Agency (2021)

3.2. Description of Experimental Materials

3.2.1. Plant 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 (Table 1). The varieties were selected based on their wide scale production by the farmers and their production potential in the study area.

Table 1: Descriptions of potato varieties used for the study

Name of variety	Year of release	Rainfall (mm)	Altitude	Maturity time	Yield t ha^{-1}(research)	Breeder/Maintainer
Belete	2009	750-1000	1600- 2800	110-120	47.19	HARC/ EIAR
Gudanie	2006	750-1000	1600- 2800	110-120	29.2	HARC/ EIAR
Local	-	-	-	-	-	-

Source: MoA, 2013

3.2.2. Fertilizer materials

Blended fertilizer NPSB (18.9% N, 37.7% P_2O_5, 6.95% S and 0.1% B) and urea (46% N) were used as source of fertilizers.

3.3. Treatments and Experimental Design

The experiment had four rates of NPSB (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 used for all experimental plots uniformly. The experiment was laid down in Randomized Complete Blok Design (RCBD) in a factorial arrangement (4×3) with three replications. each plot had 3.75m width and 2.4m 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 m and 0.3 m between rows and plants, respectively (EIAR, 2007). The distance between the plots and blocks were kept at 1m and 1.5m 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 m × 2.25m (4.05 m^2).

3.4. 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 assigned to the experimental units within a block at random. According to the treatments, all of the blended NPSB fertilizer and a third of the 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 as per the recommendations for potato production.

3.5. Data Collection

3.5.1. Soil Sampling and Analysis Procedures

Before planting, representative soil samples were taken from the experimental field at a depth of 0-30 cm using an auger in a zigzag pattern from twenty spot, and a composite soil sample was made. The composite soil sample was labeled with necessary information and transported to the laboratory. 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 analyze at Wolkite Soil Laboratory, and available sulfur and boron at Hawassa Soil Laboratory using standard procedures.

Soil texture was analyzed by determining the percentage of sand, silt and clay of the soil sample by following Bouyoucos hydrometer method (Bouyoucos, 1962), after destroyed organic matter using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexameta phosphate ($NaPO_3$). 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) in which the sample was first digested with potassium dichromate in sulfuric acid solution and titrated with 0.5 N ferrous sulfate solution, and percent 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 Kjeldahl method as described by Black (1965). Available phosphorus was determined using the Olsen method (Olsen *et al*., 1954). Available sulfur was determined by mono-calcium phosphate extraction method (Hoeft *et al*., 1973) and available boron was determined using hot water method (Havlin *et al*., 1999).

3.5.2. Agronomic Data Collection

The following data on growth, yield components, yield, and certain quality attributes were collected and collated to determine the response of potato varieties to NPSB fertilizer rates.

3.5.2.1. Phenological parameters

(a) 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).

(b) 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).

(c) 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).

3.5.2.2. Growth parameters

(a) 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.

(b) Number of main stems (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 flowering (Zelalem *et al*., 2009) and the mean number of stem per hill was computed.

3.5.2.3. Yield and yield components

(a) 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).

(b) 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.

(c) Marketable tuber yield (t ha^{-1}): Tubers which are free of diseases, insect pest damages and above 25g in weight are considered as 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.

(d) Unmarketable tuber yield (t ha^{-1}): Tubers which are diseased and insect pest attacked and less than 25g, misshaped and decayed are considered as unmarketable tuber as

indicated by Lung' aho *et al*. (2007). The weight of such tubers harvested from net plot area was measured using scaled balance and expressed as ton per hectare.

(e) 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).

(f) 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).

3.5.2.4. Quality parameters

(a) Tuber dry matter content (%): Ten tubers representing all size categories, were chopped into small sized 1-2 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 hrs for pre drying; and further dry at 105°C until constant weight attained and expressed in percent method as described by Zelalem *et al*. (2009).

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

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

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

(c) 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).

3.6. 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 the Duncan's multiple range test (DMRT) at 5% probability. Pearson correlation analysis between each parameters studied was carried using SAS software.

3.7. Economic Analysis

The partial budget analysis was done for economic analysis as described by CIMMYT (1988). The economic advantages of applied blended NPSB fertilizer and varieties were carried out using partial budget analysis. In this experiment, cost of varieties and NPSB cost were considered as variable costs. However, other management and fixed costs were assumed to be equal for all and not included in the calculation. Dominance analysis was carried out by listing the treatments in order of increasing the total variable costs to calculate marginal rate of return. According to CIMMYT (1988) any treatments that have net benefits less or equal to the previous treatment was denominated and discarded for further analysis. The economic analysis was based on the formula developed by CIMMYT (1988) and given as follows:

Average Marketable Tuber Yield (t ha^{-1}) (AMTY): It was an average marketable tuber yield of each treatment.

Adjusted Marketable Tuber Yield (AJMTY): It was the average marketable tuber yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers. **AJMTY = AMTY- (AMTY*0.1)**.

Gross Field Benefit (GFB): It was computed by multiplying field/farm gate price that farmers receive for the crop when they sale it as adjusted yield. **GFB=AJMTY*field/farm gate price**.

Total cost: Costs of NPSB fertilizer and variety cost were variable costs of the experiment and their prices were based on the experimental period

Net Benefit (NB): It was calculated by subtracting the total costs from gross field benefits for each treatment. **NB = GFB - Total cost**.

Marginal Rate of Return (MRR %): It was calculated by dividing change in net benefit by change in cost which was the measure of increasing in return by increasing input.

4. RESULTS AND DISCUSSION

4.1. Soil Physicochemical Properties of the Experimental Site

The analyzed soil texture and chemical properties of the experimental site before planting are indicated in Table 2. The soil texture of the experimental site had 35% sand, 40% silt, and 25% clay. The soil was classified under loam soil texture according to USDA (1987) textural classification. The soil pH of the experimental field showed that the field has a pH value of 5.65, which is under moderately acid category. According to Hazelton and Murphy (2016), pH values classified as pH ≤ 4.0 extremely acidic, 4.0-5.5 very strongly and strong acid, 5.5-7.3 moderately acidic, slightly acidic and neutral, 7.3-8.5 slightly and moderately alkaline, and pH values ≥8.5 strongly and very strongly alkaline. Hence, soil pH is a very import soil property due to its ability to determine the availability of nutrients for plant uptake (El-Attar *et al*., 1973). Different soil nutrients are available for uptake by plants at different soil pH levels. Some soil nutrients are available at acidic pH while others are available at alkaline pH levels. The Soil pH level that allows for a wider nutrient availability to crops is in the 5.5 to 7.5 range (Chopra and Kanwar, 1976).

The CEC of the experimental site was 31 cmol kg^{-1} soils, which is under high category (Hazelton and Murphy, 2007). The experimental soil was characterized by 1.93% organic carbon and 3.33% organic matters that were characterized as medium as described by Hazelton and Murphy (2016). Total nitrogen value was 0.15%. According to Goronski *et al*. (2010) described that N content of soil between 0.15-0.25 percent is medium and greater than 0.25 % is high. Available phosphorus of soil was categorized within low (7.33 ppm) which was based on the ranges rated by Hazelton and Murphy (2016). According to Lelago *et al*. (2016), available sulfur of the experimental soil is low (17.87ppm), and available boron is also low (0.092 ppm) (Benton, 2003).

Table 2: 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.

4.2. Phenological and Growth Parameters

4.2.1. Days to 50 % emergence

The analysis of variance revealed that days to 50% emergence was highly significantly ($P<0.01$) influenced by varieties but not affected by blended NPSB fertilizer rates and their interaction (Appendix Table 4).

Accordingly, local variety (*Askot*) emerged about two weeks earlier (17.17 days) compared to the improved varieties included in the present study (Figure 3). In contrast, Gudanie variety took longer days to emerge (20.17 days) followed by Belete (19.08 days); but those 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 variation in days to 50% emergence among the varieties might be attributed to the genetic variability of potato varieties in absorption of moisture and stored food in tubers. Likewise, Gezahegn *et al*., (2021) also reported varietal difference affected day to 50% emergence of potato.

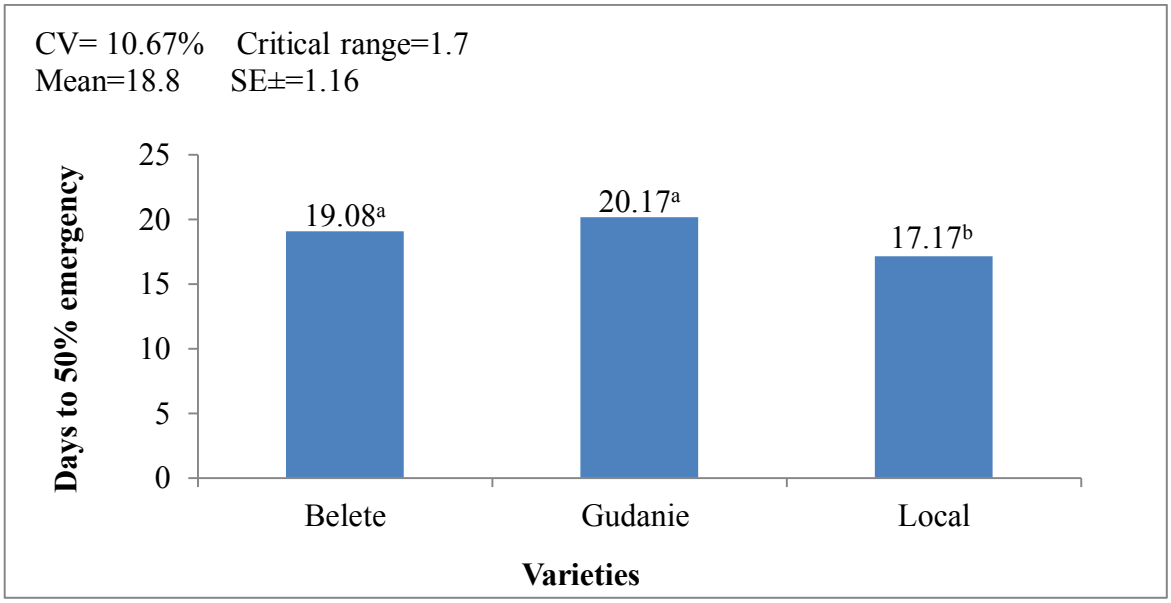


Figure 3: Main effect of varieties on days to 50% emergence

4.2.2. Days to 50% flowering

Days to flowering of potato plants were highly significantly ($P<0.01$) influenced by the main effect of varieties and blended NPSB fertilizer rates. However, their interaction had no effect on the number of days it took for potato plants to reach 50% flowering (Appendix Table 4).

Variety local (*Askot*) was significantly earlier (62.75 days) for days to 50% flowering at about 12.33 and 6.17 days from varieties Gudanie and Belete, respectively (Figure 4). The observed variation in terms of days to 50% flowering of potato varieties included in this study might be attributed to genetic variation of the varieties in completing their vegetative growth and variation in environmental adaptability among the varieties. It is known that earliness in flowering is controlled by many factors including genetic and environmental factors; mainly temperature and light (Bradshaw, 2007; Vreugdenhil, 2007). 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. Furthermore, Arega *et al*. (2017) and Tilahun (2018) reported that there are differences among varieties in terms of the vegetation period.

Regarding to blended NPSB fertilizer, the earliest days to 50% flowering (61.11 days) was recorded from the control treatment which did not received 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}, which is statistically similar with a plot that received 238 kg ha^{-1} of NPSB fertilizer (Figure 5). The results of the present study clearly indicated that increasing application rates of blended NPSB fertilizer from 0 to 357 kg ha^{-1} prolonged days to 50% flowering from 61.11 to 74.78 days. Such observed prolonged in days to 50% flowering, as a result of increasing application blended 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).

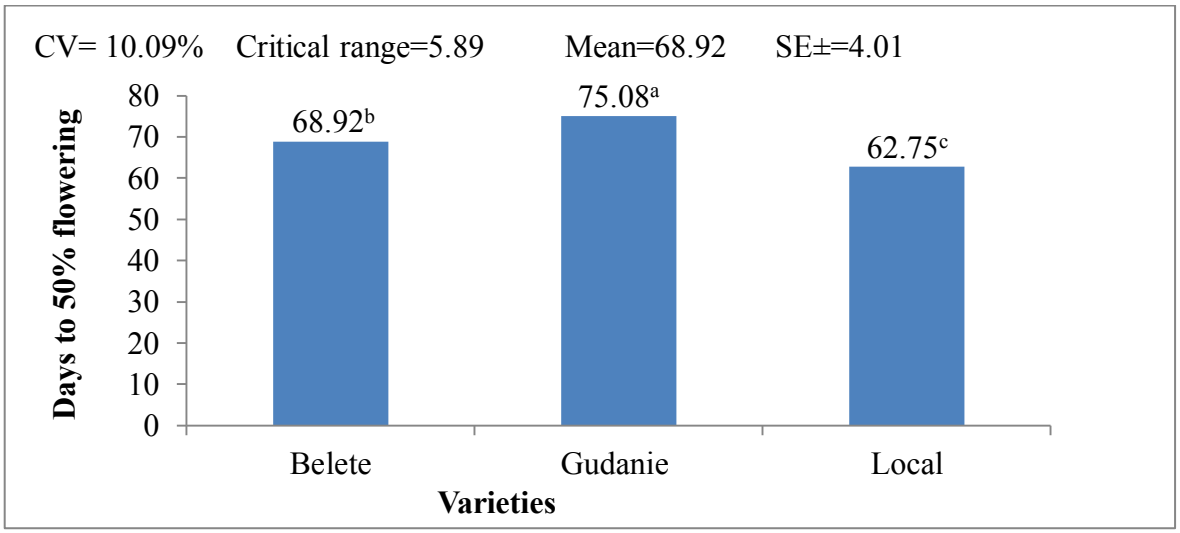


Figure 4: Main effect of varieties on days to 50% flowering

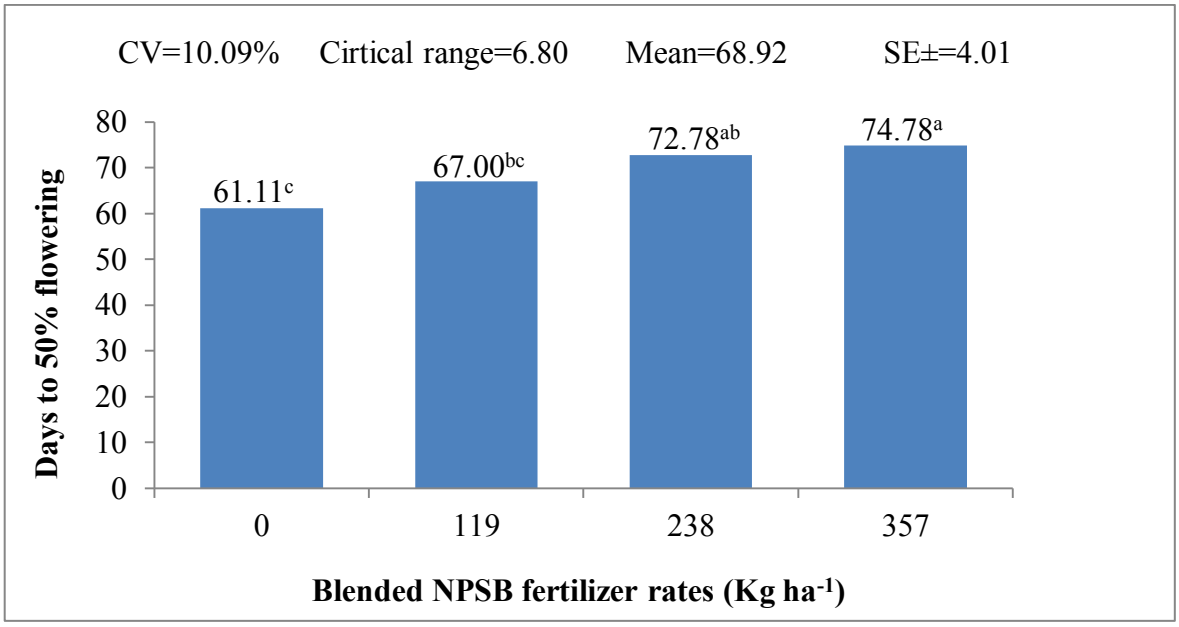


Figure 5: Main effect of NPSB fertilizer on days to 50% flowering

4.2.3. Days to 90% maturity

Days to maturity of potato were significantly ($P \leq 0.01$) influenced by the main factor of varieties, blended NPSB fertilizer rates and their interactions (Appendix Table 4).

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} with the same variety. In contrary, the earliest days to physiological maturity (95.33 days) were attained from the treatment that did not receive NPSB fertilizer (control) with the local variety (Table 3). Variety Gudanie was significantly varied in days to maturity from Belete and local variety by about 5.67 and 6 days, respectively with the same rate of NPSB fertilizer, and application of 357 kg NPSB ha^{-1} on Gudanie variety were higher by about 25.34 days compared to variety local of the control plot (unfertilized plot) in days to 90% physiological maturity. This might be the varieties had different morphological and physiological senescence due to the combined effect of genetic makeup and environments including its nutrient utilization of the crops, which attributed that the genetically variation in response to the maximum level of nitrogen in NPSB fertilizer which resulted extended physiological and photosynthesis activities and delayed maturity. Besides, number of days required to attain 90% physiological maturity of potato varieties proportionally increased with increasing blended NPSB fertilizer rates. 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 application of NPS fertilizer on improved varieties of Gudanie and Belete were late matured compared to variety local.

Table 3: Interaction effect of blended NPSB fertilizer rates and varieties on days to 90% maturity

Blended NPSB fertilizer (kg ha^{-1})	Variety		
	Local	Gudanie	Belete
0	95.33^{f}	111.67^{cd}	108.33^{ed}
119	105.00^{e}	114.33^{bc}	113.00^{cd}
238	114.00^{c}	119.33^{ba}	114.33^{bc}
357	114.67^{bc}	120.67^{a}	115.00^{bc}
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 statistically non-significant at ($P \leq 0.05$).

4.2.4. 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 (Appendix Table 5).

The longer plant height (69.54 cm) was observed in variety Belete that 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 treated with NPSB fertilizer (Table 4). Generally, in this study plant height of the tested varieties were increased at the highest level of fertilizer rates.

Accordingly, application of 357 kg NPSB ha^{-1} on Belete variety was higher by 42.64% in plant height from variety local of the unfertilized plot (0 kg NPSB ha^{-1}) (Table 4). This could be due to the genetic variation among varieties with respect to plant height with the response of the applied blended fertilizer since the variation at control treatments observed due to absence of fertilizer specially due to lack of nitrogen fertilizer which promotes plant growth. Genetic variation existed in the potato varieties used in the study, for 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, improved varieties (Belete and Gudanie) longer in height as compared to local variety with the same rate of blended NPS fertilizer in different agro-ecologies.

4.2.5. Number of main stems per hill

The analysis of variance revealed that main effects of varieties and blended NPSB fertilizer rates, and their interactions had significant ($P \leq 0.05$) influence on number of main stems per plant (hill) (Appendix Table 5).

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 4). Generally, the increment of main stems per hill was depended on genetic variability of varieties with increasing the rate of blended NPSB fertilizer. Application of 357 kg NPSB ha^{-1} on the improved varieties of Belete and Gudanie had higher number of stems than variety local by about 38.54 and 33.63%, respectively. This showed that the difference between varieties on stems number due to genetic difference in response to blended fertilizer treatments which might be the hereditary varied in nutrient utilization determines production capability of main stems number and secondary branches. Likewise the present study, Melkamu and Minwyelet (2018) demonstrated that the 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 location.

Table 4: Interaction effect of blended NPSB fertilizer rates and varieties on plant height and main stems number per hill

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

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and means followed by the same letters are statistically non-significant at ($P \leq 0.05$).

4.3. Yield and Yield Components of potato

4.3.1. Total tuber number per hill

The analysis of variance showed that the main effect of blended NPSB fertilizer rates and varieties; as well as their interactions significantly ($P \leq 0.05$) affected total tubers number per hill (Appendix Table 5). At a rate of 238 kg NPSB ha^{-1}, variety Gudanie produced the highest total tuber number per hill (15.39). However, the local variety with the unfertilized plot had the lowest tubers number per hill (7.65), which was statistically similar to a variety Belete that did not get NPSB fertilizer (Table 5).

In general, the number of tubers per hill for the tested varieties increased as the rate of blended NPSB fertilizer increased from zero to 238 kg ha^{-1}, which is optimum for the improved varieties of Belete and Gudanie, but beyond 119 kg ha^{-1} application on local variety, number of tubers decreased without statistical difference due to varietal differences in nutrient uptake. With the same application rate of blended NPSB fertilizer (238 kg ha^{-1}), the maximum total tuber number per hill obtained from Gudanie was statistically higher than varieties Belete and local by about 14.81 and 25.4%, respectively; and application of

238 kg NPSB ha^{-1} on Gudanie variety was higher by about 50.29 % when compared to unfertilized plots of local variety (Table 5). This could be attributable to genetic heterogeneity across varieties in terms of producing tuber number per hill in response to blended NPSB fertilizer application, as well as differences in the availability of balanced nutrients for better tuber initiation, resulting in the highest tuber number per hill. The findings are consistent with those of Gezahegn *et al*. (2021), who found that variety Gudanie produced more tubers per hill than variety Bubu at the same application rate (200 kg NPSB ha^{-1}) due to genetic differences.

4.3.2. Tuber yield per hill (kg $hill^{-1}$)

The main effect of blended NPSB fertilizer rates and varieties, as well as their interactions, had a significant ($P \leq 0.01$) influence on tuber yield per hill (Appendix Table 5). Variety Belete produced the highest tuber yield per hill (1.773 kg $hill^{-1}$) with 238 kg NPSB ha^{-1}, which was statistically similar to the same variety receiving 357 kg ha^{-1} of blended NPSB fertilizer. On the other hand, the lowest tuber yield per hill (0.682 kg $hill^{-1}$) was observed from the local variety with the unfertilized plot, which was statistically in parity with the same variety that received 119 kg NPSB ha^{-1}, and that of unfertilized plot of Gudanie variety (Table 5).

All the tested potato varieties of tuber yield per hill were increased with increasing rates of NPSB fertilizer from 0 to 238 kg ha^{-1} (Table 5). However, increasing the application rates beyond 238 kg NPSB ha^{-1} did not significantly increased tuber yield per hill in all tested varieties, and tuber yield of the tested varieties varied in response to the application rates of NPSB fertilizer. This might be the genetic makeup of the crops varied in accumulation of food material accumulation (nutrient uptake), as well as photosynthetic activity responded 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 yield per hill.

Table 5: Interaction effect of blended NPSB fertilizer rates and varieties on total tuber number per hill and tuber yield per hill

Blended NPSB fertilizer (kg ha^{-1})	Total tuber number (tuber hill^{-1})			Tuber yield (kg hill^{-1})		
	Variety					
	Local	Gudanie	Belete	Local	Gudanie	Belete
0	7.65^{g}	9.83^{f}	8.07^{g}	0.682^{f}	0.801^{def}	0.933^{cde}
119	11.51^{ced}	12.16^{cbd}	10.74^{efd}	0.759^{ef}	1.026^{c}	1.107^{b}
238	11.48^{ced}	15.39^{a}	13.11^{b}	0.989^{cd}	1.443^{b}	1.773^{a}
357	10.56^{ef}	13.65^{b}	12.66^{cb}	0.920^{cde}	1.423^{b}	1.583^{ab}
Mean	11.40			1.12		
Critical range	1.38			0.19		
SE±	0.47			0.065		
CV (%)	7.12			10.1		

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and means followed by the same letters are statistically non-significant at ($P \leq 0.05$).

4.3.3. Tuber Size Distribution

4.3.3.1. Yield of small sized tubers (t/ha)

The analysis of variance revealed that both varieties and blended NPSB fertilizer rates influenced the yield of small sized (25-38 g) tubers in a highly significant ($P<0.001$). The interaction effect of varieties and blended NPSB fertilizer rates, on the other hand, had no significant effect on the yield of small sized tubers (Appendix Table 6).

The local variety had the largest yield (5.06 t ha^{-1}) of small sized tubers, whereas the Belete variety produced the lowest yield (3.08 t ha^{-1}) of small size tubers (Figure 6). The observed differences in small sized tuber production between varieties could be attributed to genetic variability as well as environmental factors (Kumar *et al*., 2007; and Alemayehu *et al*., 2018). In contrast to this study, Sadik *et al*. (2018) observed that the improved Gudanie cultivar yielded more small sized tubers than the local variety.

The application of 119 kg NPSB ha^{-1} resulted in the largest yield of small size tubers (4.87 t ha^{-1}), which was statistically similar to the control treatment (unfertilized plots); however,

the plot treated with 357 kg ha^{-1} of NPSB fertilizer yielded the lowest yield of small sized tubers (2.9 t ha^{-1}) (Figure 7). This implied that the low nutrient rate resulted in a higher yield of small sized tubers. When compared to the plot treated with 119 kg ha^{-1} NPSB, the application of 357 kg NPSB ha^{-1} reduced yield of small sized tubers by 40.45%. This result showed that blended NPSB fertilizer increased the size of potato tubers, which could be due to increased phosphorous levels, which may play a role in increasing above ground biomass via photosynthesis and net assimilation processes, and re-absorption did not occur from tuber (Gezahegn *et al*., 2021), resulting in increased tuber size and weight, and decreased yield of small sized tubers. 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%.

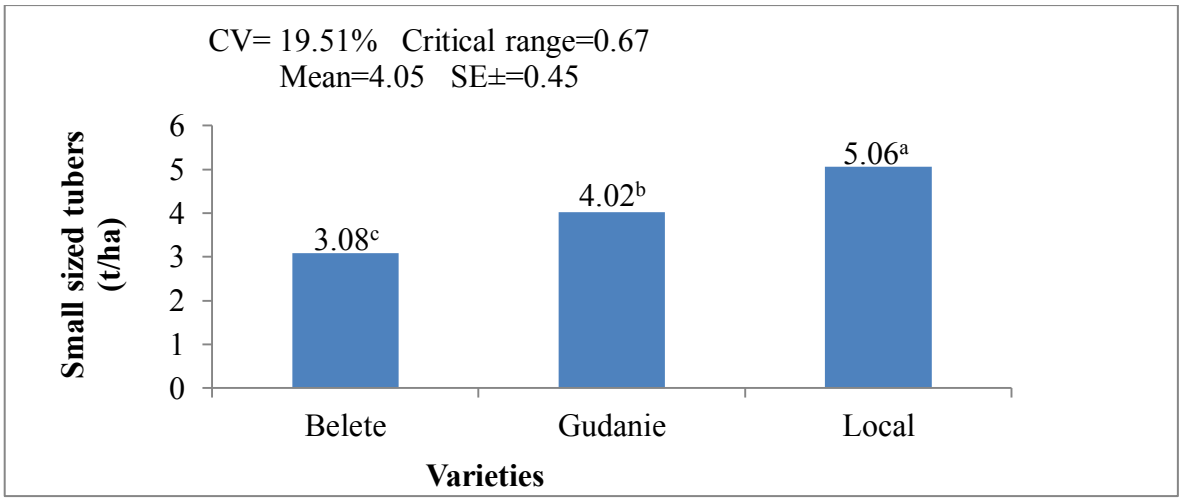


Figure 6: Main effect of varieties on small sized tuber yield

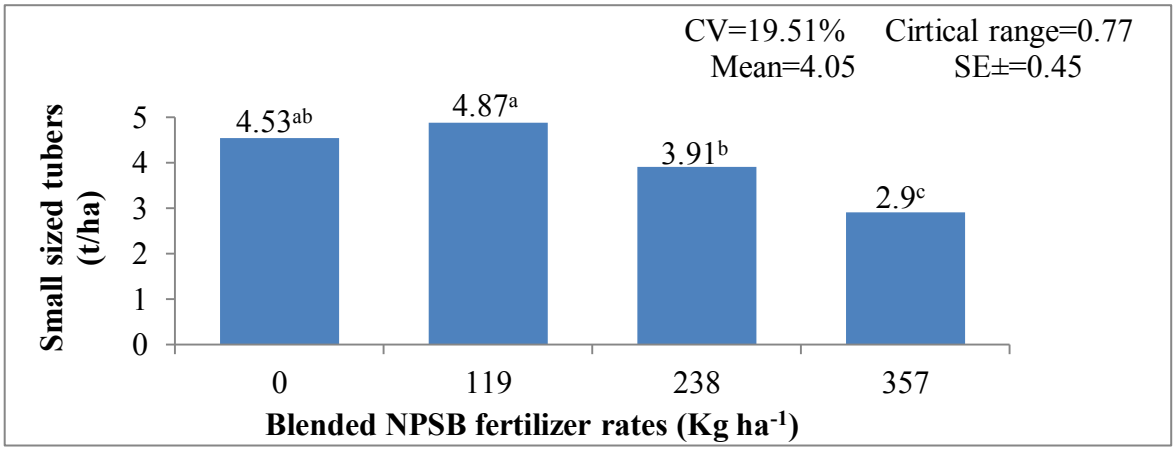


Figure 7 : Main effect of NPSB fertilizer rates on small sized tuber yield

4.3.3.2. Yield of medium sized tubers (t/ha)

Yield of medium sized (39-75 g) tubers were significantly ($P<0.001$) affected by main effects of varieties and blended NPSB fertilizer, while their interactions was not significant different (Appendix Table 6). The Gudanie variety gave the largest yield (10.86 t ha^{-1}) of medium sized tubers, while the lowest (7.05 t ha^{-1}) was recorded from local variety (Figure 8). The difference in medium size tuber yield among the tested potato varieties could be associated with the genetic makeup of the varieties which is line with the findings of Struick *et al*. (2000) and Sharma *et al*. (2013).

The highest yield of medium sized tubers (11.99 t ha^{-1}) was obtained from plants which supplied with 238 kg ha^{-1} of NPSB fertilizer rate, and it was statistically at par with 357 kg NPSB ha^{-1}. In contrast, the lowest yield of medium sized tubers (5.28 t ha^{-1}) was recorded from unfertilized plot (Figure 9). The results showed that increasing the rate of blended NPSB fertilizer enhanced medium size tuber production up to a rate of 238 kg NPSB ha^{-1}, but that above this rate, there was no benefit in medium size tuber yield. The increment of NPSB fertilizer rates, which might have positive response on tuber initiation process and bulking rates of tubers, including the size and shape of tubers, could explain the incremental yield of medium sized tubers due to increased NPSB rates to some extent and the decrease at the highest rate (357 kg NPSB ha^{-1}). In line with this finding, Gezahegn *et al*. (2021) reported that, increasing the rates of blended NPSB fertilizer from 0 to 200 kg ha^{-1} increased the proportion of medium sized tubers by 29.83 to 42.97%; however, beyond this rate, no significant differences in the proportion of medium size tubers were observed. Moreover, other scholar observed 34.32 to 37.53% increase medium size tubers of potato as the NPSB application increased from 0 to 200 kg ha^{-1} (Wassie and Tekalign, 2013).

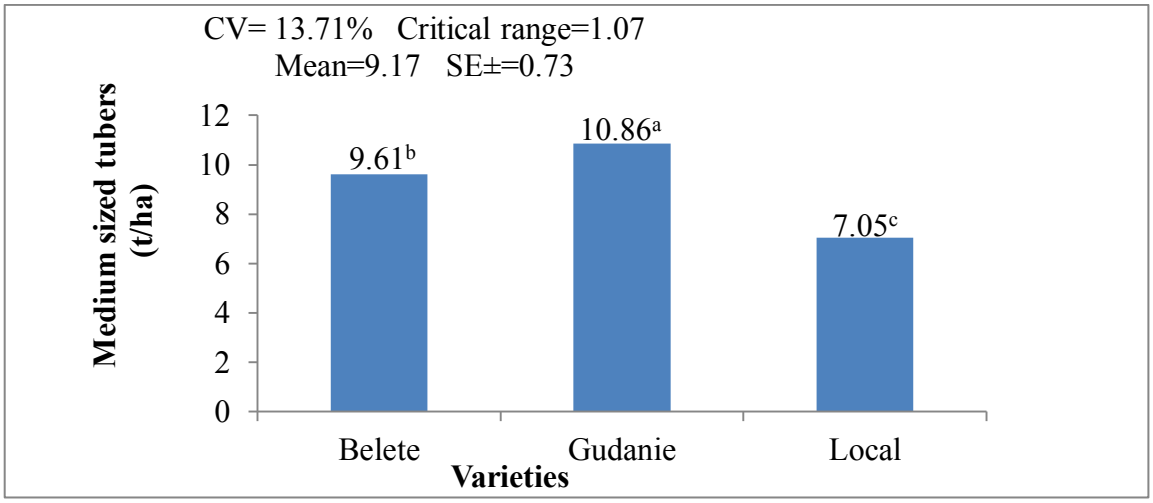


Figure 8: Main effect of varieties on medium sized tuber yield

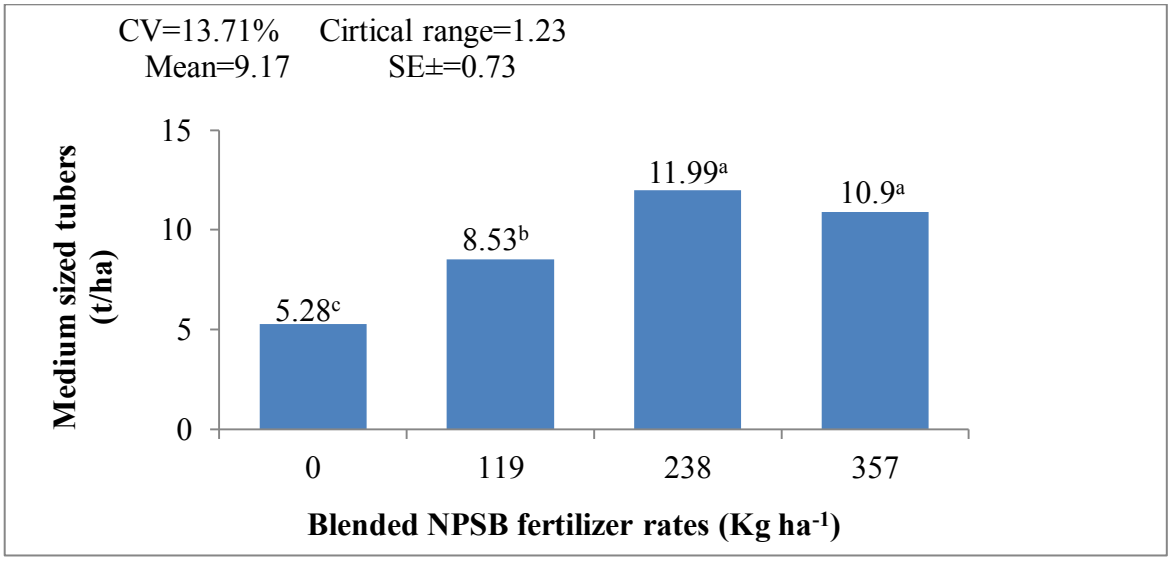


Figure 9: Main effect of NPSB fertilizer rates on medium sized tuber yield

4.3.3.3. Yield of large sized tubers (t/ha)

The main effects of blended NPSB fertilizer rates and varieties, as well as their interaction, influenced the yield of large sized tubers (>75g) significantly (P<0.001) (Appendix Table 6).

The maximum yield of large sized tubers (21.33 t ha^{-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 6). Almost all the tested potato varieties of large sized of tuber yield increased with increasing the application rate of blended NPSB fertilizer from 0 to 357 kg ha^{-1}. However, applying 357 kg NPSB ha^{-1} to variety Belete resulted in a 55.46 and 60.29% higher production of large tubers than varieties Gudenie and local, respectively. 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.

Table 6: Interaction effect of blended NPSB fertilizer rates and varieties on yield of large sized tubers and marketable tuber yield

Blended NPSB fertilizer (kg ha^{-1})	Yield of large sized tubers (>75g)			Marketable tuber yield (t ha^{-1})		
	Variety					
	Local	Gudanie	Belete	Local	Gudanie	Belete
0	2.02^{e}	3.89^{ed}	7.78^{cb}	11.48^{g}	13.32^{gf}	16.72^{edf}
119	3.17^{e}	6.35^{cd}	8.93^{cb}	15.77^{egf}	21.23^{cd}	20.03^{cde}
238	8.57^{cb}	9.20^{cb}	19.41^{a}	21.38^{cd}	27.70^{b}	34.30^{a}
357	8.47^{cb}	9.50^{b}	21.33^{a}	21.10^{cd}	24.21^{cb}	33.91^{a}
Mean	9.05			21.76		
Critical range	2.78			4.52		
SE±	0.95			1.54		
CV (%)	18.10			12.26		

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and means followed by the same letters are statistically non-significant at ($P \leq 0.05$)

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

The analysis of variance revealed that the main and interaction effects of potato varieties and blended NPSB fertilizer rates influence marketable tuber yields significantly ($P \leq 0.05$) (Appendix Table 7). In interaction effect, application of optimum rate of NPSB (238 kg ha^{-1}) on variety Belete produced maximum marketable tuber yields (34.30 t ha^{-1}) and which

was statistically similar with application of 357 kg NPSB ha^{-1} on the same variety. On the other hand, the lowest marketable tuber yield was recorded on varieties local (11.48 t ha^{-1}) and Gudanie (13.32 t ha^{-1}) with the unfertilized plots, and which was significantly at par with variety local which received 119 kg ha^{-1} of blended NPSB fertilizer (Table 6).

According to the finding of this study, increasing the rates of blended NPSB fertilizer from 0 to 238 kg ha^{-1} increased marketable tuber yield of varieties local, Gudanie, and Belete by 46.30%, 51.91%, and 51.25%, respectively, but marketable tubers yield decreased without statistical difference beyond this rate (Table 6). However, application 238 kg ha^{-1} of NPSB on variety Belete resulted in a 66.53 % higher maximum marketable tuber yield than using variety local without fertilizer. The difference in potato marketable tuber yields among these varieties in response to applied blended NPSB fertilizer, which could be related to their genetic makeup in efficient 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 in marketable tubers size and weight. 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 tuber yield of varieties Bubu and Gudanie by 7.83 and 11.89 t ha^{-1}, respectively. Likewise, Melkamu and Minwyelet (2018) reported that, application of 283.75 kg ha^{-1} NPS fertilizer increased marketable tuber yield by 174.2% and 155.5% in varieties Belete and Gudanie respectively, as compared to the respective unfertilized plants.

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

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 (Appendix Table 7).

Improved varieties of Belete and Gudanie produced lower unmarketable tuber yield by about 18.1 and 15.62%, respectively as compared to the farmer's local variety (Figure 10). This might be the genetic capacity of the cultivar to improve the size and weight of the tubers, adaptability, crop maturity, and the inherent ability of the variety in producing 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. Differences in potato unmarketable tuber yield,

which is attributable to variety heterogeneity, were also observed (Berhanu and Tewodros, 2016; Seifu and Betewulign, 2017). 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 (Figure 11). 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 increasing the rates of blended NPSB fertilizer, the unmarketable tuber yield of potato became decreased. Similarly, Desta (2018) reported that increasing the rates of blended NPS fertilizer from 0 to 100 kg ha^{-1} significantly decreased unmarketable tuber yield of potato.

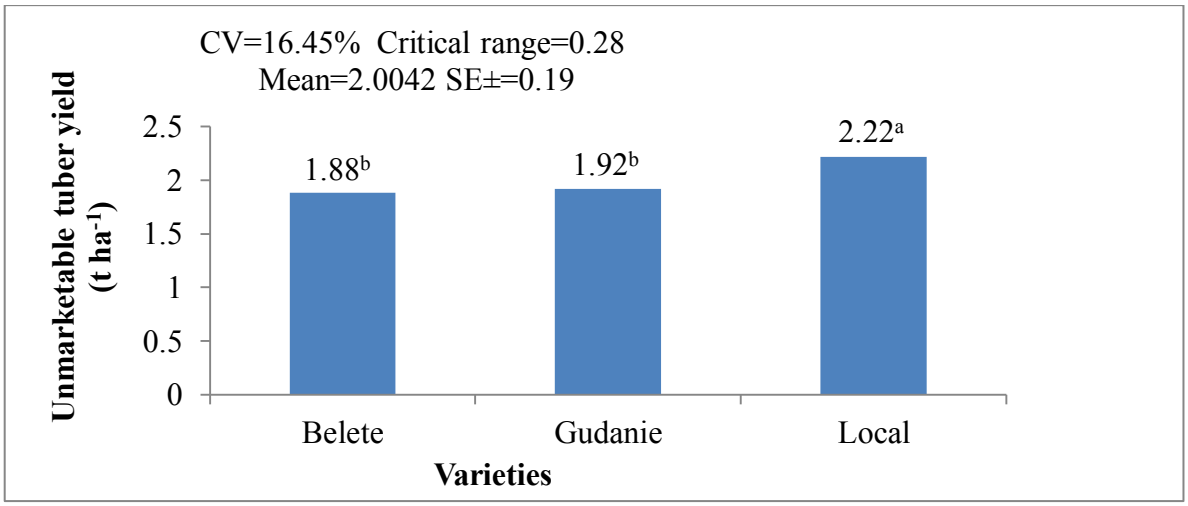


Figure 10: Main effect of varieties on unmarketable tuber yield

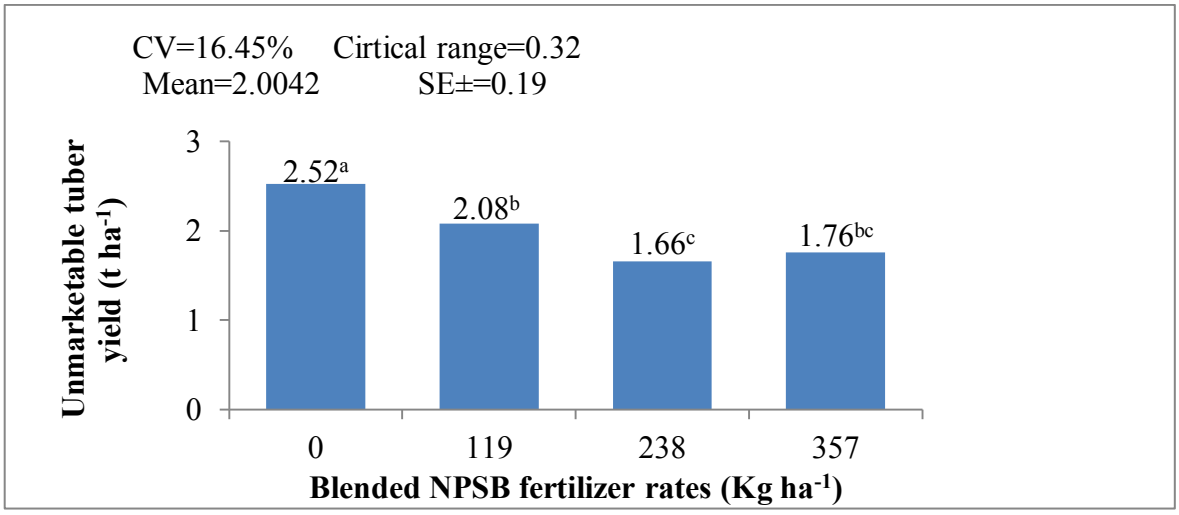


Figure 11: Main effect of NPSB fertilizer rates on unmarketable tuber yield

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

Both the main effects of blended NPSB fertilizer rates and varieties, as well as their interaction effects, had a significant ($P \leq 0.05$) influence on potato tuber yield (Appendix Table 7). NPSB rate of 238 kg ha^{-1} applied on variety Belete produced the highest total tuber yield (35.84 t ha^{-1}) of potato, which was statistically similar to 357 kg NPSB ha^{-1} applied on the same variety. The lowest total tuber yield (14.40 t ha^{-1}) was recorded from local variety with unfertilized plots, which was statistically similar to the same variety with 119 kg ha^{-1} NPSB, and that of Gudanie and Belete varieties with unfertilized plots (Table 7).

Total tuber yield of potato varieties increased by about 38.17% local, 46.03% Gudanie and 47.32% Belete with the application rate of 238 kg ha^{-1} NPSB fertilizer compared to the respective control (unfertilized) plots (Table 7). However, increasing the application rate of blended NPSB fertilizer beyond 238 kg ha^{-1} did not bring significant advantage in all tested varieties. The variations in yield among the varieties respond to applied NPSB fertilizer might be their genotypes differ in absorption and utilization of nutrients and it revealed that NPSB fertilizer increased total tuber yields of potato varieties till its optimum rates of the genotype increasing photosynthetic activity and translocation of photosynthetic product to the root, which might have helped in the initiation of more stolen on potato, and promote increasing tuber yield (Karenlampi and White, 2009). Muluneh (2018) reported that the maximum total tubers yield was obtained when 300 kg NPSB ha^{-1} was applied to the variety Belete, whereas the lowest yield was obtained from unfertilized plots of Jalene,

Gudanie, and Belete. Furthermore, Gezahegn *et al*. (2021) reported that the highest potato tubers yield obtained from variety Gudanie at 200 kg NPSB ha^{-1} and lowest from variety Bubu on unfertilized plots. The total tuber yields of the tested potato varieties increased when NPS fertilizer application rates were increased in different experimental location (Melkamu and Minwyelet, 2018). This result agree with the findings of Gezahegn *et al*. (2021) reported, increased blended NPSB fertilizer rates from 0 to 200 kg ha^{-1} increased total tubers yield of Bubu and Gudanie varieties by 7.73 and 10.22 t ha^{-1}, respectively.

Table 7: Interaction effect of blended NPSB fertilizer rates and varieties on total tuber yield (t ha^{-1})

Blended NPSB fertilizer (kg ha^{-1})	Variety		
	Local	Gudanie	Belete
0	14.40^{f}	15.78^{f}	18.88^{edf}
119	17.91^{ef}	23.27^{cd}	22.09^{cde}
238	23.29^{cd}	29.24^{b}	35.84^{a}
357	23.01^{cd}	25.84^{cb}	35.65^{a}
Mean	23.77		
Critical range	4.63		
SE±	1.58		
CV (%)	11.49		

Where: SE (±) = Standard Error; CV (%) = Coefficient of Variation; and means followed by the same letters are statistically non-significant at ($P \leq 0.05$)

4.4. Quality Attributes of Potato

4.4.1. Specific gravity of potato tubers

Main effects of varieties and blended NPSB fertilizer rates had significant ($P<0.05$) effect on specific gravity of the tubers. However, the interaction of blended NPSB fertilizer rates and varieties did not show significant effect on tuber specific gravity (Appendix Table 8).

The highest tuber specific gravity (1.089 g/cm^3) was recorded for variety Belete, while the lowest (1.074 g/cm^3) obtained from local variety (Figure 12). This may be due to genetic differences among the varieties; according to Burton (1966) reported, genetic differences among varieties play a role in their ability to produce high solids. 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 the lowest (1.074 g/cm^3) recorded on unfertilized plots (Figure 13). The increment of tuber specific gravity with higher rates 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 significant effect on tuber specific gravity. 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. Likewise, tuber specific gravity of potato was highly significantly increased with the increasing fertilizer rates (Zelealem *et al*., 2009; Tesfaye *et al*., 2013).

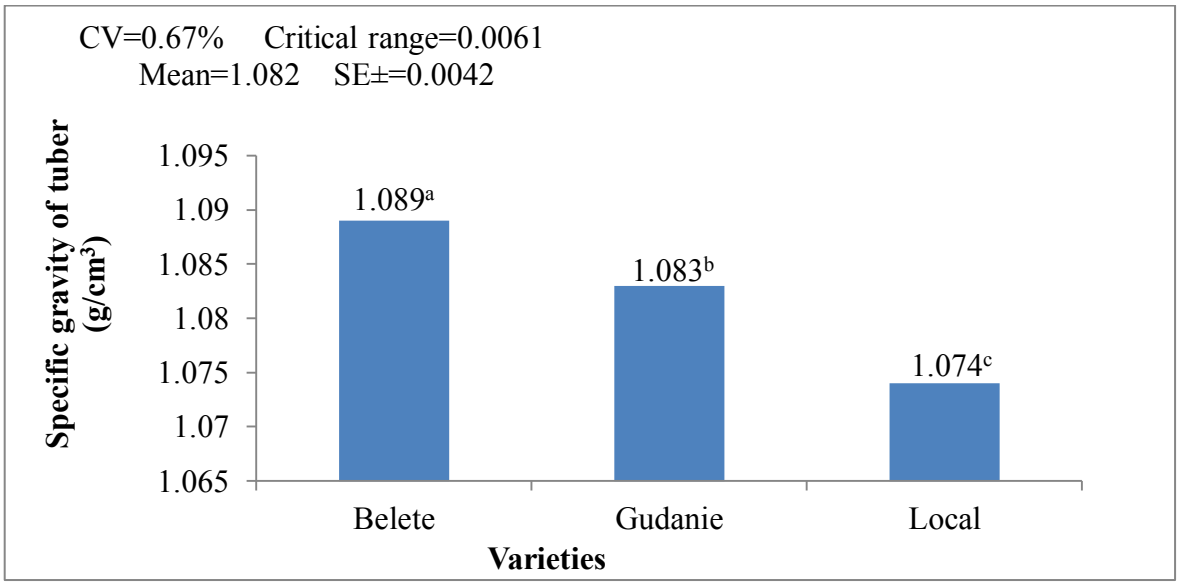


Figure 12: Main effect of varieties on tuber specific gravity

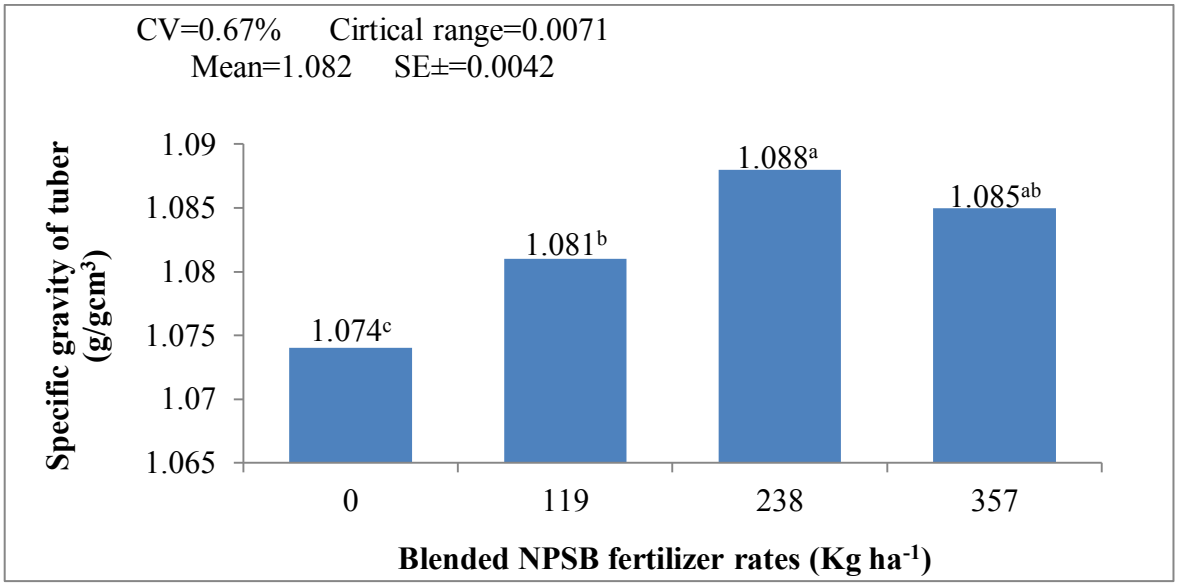


Figure 13: Main effect of NPSB fertilizer rates on tuber specific gravity

4.4.2. 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 interaction (Appendix Table 8).

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 8). 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 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. The difference in tuber dry matter content among potato varieties is due to their genetic differences in response to the applied NPSB fertilizer rates which might be play a role in enhancing their ability to produce high solids. Similarly, Melkamu and Minwyelet (2018) reported, 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 varieties across the NPS application rates and locations.

Table 8: Interaction effect of blended NPSB fertilizer rates and varieties on potato tuber dry matter content

Blended NPSB fertilizer (kg ha^{-1})	Variety		
	Local	Gudanie	Belete
0	18.83^{d}	22.50^{cb}	21.42^{c}
119	19.16^{d}	23.33^{cb}	23.33^{cb}
238	22.16^{cb}	23.67^{cb}	26.75^{a}
357	22.50^{cb}	22.83^{cb}	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 letters are statistically non-significant at ($P \leq 0.05$).

4.4.3. Total starch content of potato tubers

Total starch content of potato tubers was very highly significantly ($P<0.001$) influenced by main effect of varieties and blended NPSB fertilizer rates, while their interaction was not significant (Appendix Table 8).

From the main effect of varieties, tubers of variety Belete significantly had the highest total starch content than varieties Gudanie and local by about 8.06 and 18.94%, respectively (Figure 14). The variation among varieties might be associated with variation in genetic makeup of the varieties to produce starch contents. Similarly, Wassu (2016) reported, the genotypic differences of potato had influence on tuber starch content as well as internal quality traits. On the other hand, the application of 238 kg NPSB ha^{-1} was obtained the highest tuber starch content (15.48g/100g), which were higher by 18.86%, compared to the control (unfertilized) plots (Figure 15). However, beyond 238 kg NPSB ha^{-1} did not significantly increased tuber starch contents, which might be low partitioning of assimilate to tubers and availability of sulfur and boron facilitates uptake and use efficiency of plants to nitrogen as results it decreases the solid constituent like protein, carbohydrate and fiber of tuber and increases the water content of tubers (Kandil *et al*., 2011). Furthermore, an excess of nitrogen at later stages of growth will keep the crop growing, delaying maturity

and perhaps reducing starch content, lowering the quality of the processing potato crop. In consistent with this result, Gezahegn *et al*. (2021) reported, tuber starch content increased with increasing blended NPSB fertilizer rates up to 200 kg ha^{-1}.

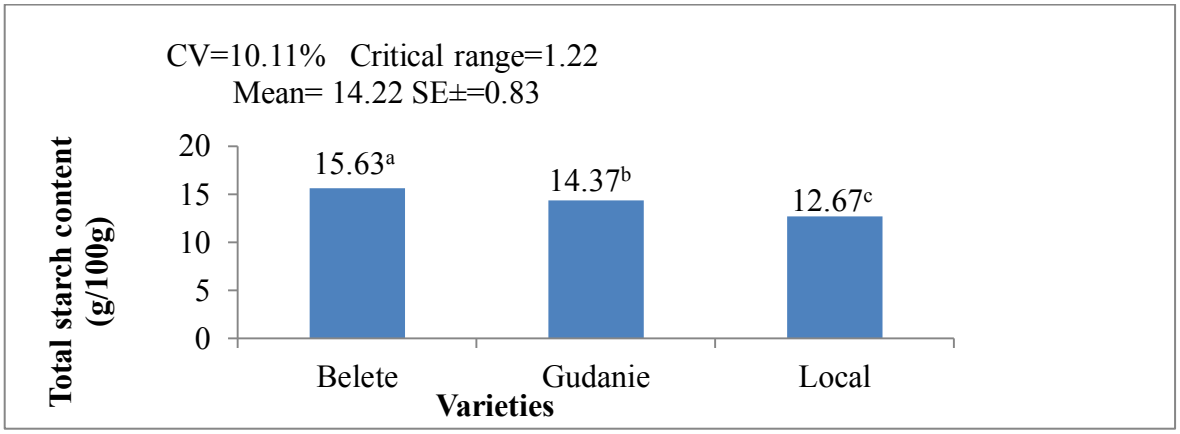


Figure 14: Main effect of varieties on total tuber starch content

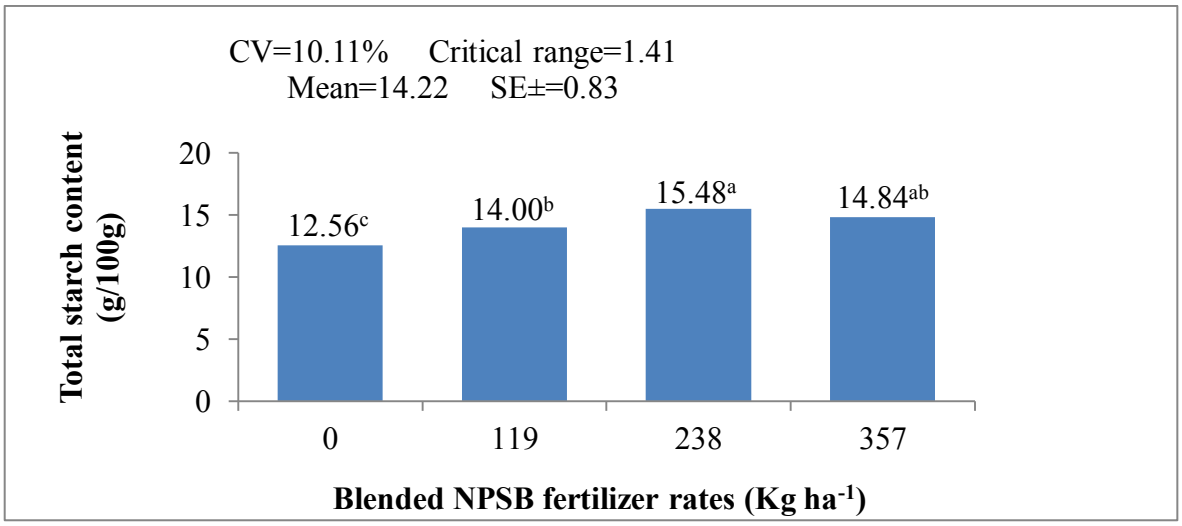


Figure 15: Main effect of NPSB fertilizer rates on total tuber starch content

4.5. Correlation Analysis on Growth, Yield and Yield Components of Potato

The analysis of correlation between growth, yield parameters and yield are indicated in Table 9. Total tuber yield of potato was significantly (P<0.001) and positively correlated with days to 90% maturity (r = 0.59***), plant height (r = 0.71***), main stem number per hill (r = 0.80***), tuber number per hill (r = 0.67***), tuber yield per hill (r = 0.87***), medium sized tuber yield (r = 0.83***), large sized tuber yield (r = 0.92***), marketable tuber yield (r = 0.99***), tuber specific gravity (r =0.71***) and tuber dray matter (r = 0.66***). In contrast, total tuber yield was significantly (P≤ 0.01) and negatively correlated

with small sized tuber yield (r = -0.51**) and unmarketable tuber yield (r = -0.59***). The possible reason for the observed association between total tuber yield and positively correlated variables might be increasing plant height and number of stems produced higher photosynthesis, which in turn resulted in vigorous vegetative growth and gave higher total tuber yield. Generally, Positively correlated parameter showed that the yield was increased they as yield related parameter increased while negatively correlated parameters showed that yield increased the parameters decreased as indicated by Zelealem *et al*., (2009).

Table 9: 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**	-0.26ns	-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.

4.6. 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 10). The result of 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 increases up to 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.

Table 10: Economic analysis of potato production as influenced by variety and NPSB fertilizer rates in Gummer District, Enjefo *kebele,* 2021 *Belg* season

Variety	NPSB (kg ha^{-1})	Average marketable yield (t ha^{-1})	Adjusted marketable yield (t ha^{-1})	Gross field benefits (birr ha^{-1})	Variety cost (birr ha^{-1})	NPSB cost (birr ha^{-1})	Total variable cost (birr ha^{-1})	Net Benefits (birr ha^{-1})	Marginal Rate of Return (%)
Local	0	11.48	10.33	74376	23733.3	0	23733.3	50642.7	-
Local	119	15.77	14.19	102168	23733.3	1868.3	25601.6	76566.4	1387.6
Local	238	21.38	19.24	138528	23733.3	3736.6	27469.9	111058.1	1846.2
Local	357	21.10	18.99	136728	23733.3	5604.9	29338.2	107389.8	D
Gudanie	0	13.32	11.99	86328	34133.3	0	34133.3	52194.7	D
Gudanie	119	21.23	19.11	137592	34133.3	1868.3	36001.6	101590.4	2643.88
Belete	0	16.72	15.05	108360	37866.7	0	37866.7	70493.3	D
Gudanie	238	27.70	24.93	179496	34133.3	3736.6	37869.9	141626.1	2222
Belete	119	20.03	18.03	129816	37866.7	1868.3	39735	90081	D
Gudanie	357	24.21	21.79	156888	34133.3	5604.9	39738.2	117149.8	8459
Belete	238	34.30	30.87	222264	37866.7	3736.6	41603.3	180660.7	3405.23
Belete	357	33.91	30.52	219744	37866.7	5604.9	43471.6	176272.4	D

Note: 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}; and D= Dominated treatment.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. 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 size of 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 decreased 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 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 marginal rate of return (3405.23%) which is economically feasible for potato production in the study area.

5.2. 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 condition, across more locations and years/seasons as to come up with a more conclusive recommendation for the study area.

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7. APPENDICES

Appendix Table 1: Monthly and yearly total rainfall (mm) at the study area (2011-2020)

	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	0.0	0.0	77.5	57.2	238.3	312.9	257.6	221.1	115.4	8.9	41.3	0.0
2012	0.0	0.0	6.9	45.7	47.9	224.8	257.5	219.1	168.0	17.3	8.2	2.2
2013	3.8	7.0	28.9	75.3	140.1	201.1	241.5	255.5	218.0	72.3	14.6	0.0
2014	3.6	72.0	45.1	93.9	206.2	122.7	210.8	216.7	197.5	119.1	11.0	0.0
2015	0.0	0.0	25.6	10.9	178.2	277.1	209.9	214.2	158.4	22.3	16.8	28.8
2016	32.0	12.3	25.7	177.8	172.3	106.3	230.4	241.3	160.0	96.1	10.1	0.0
2017	0.0	57.9	25.8	69.6	245.1	213.5	229.3	256.7	159.7	48.2	12.7	0.0
2018	3.7	60.7	49.5	110.2	94.8	339.8	254.7	232.6	225.2	42.3	66.1	1.2
2019	0.0	31.3	54.0	228.4	104.0	219.9	235.4	270.3	237.0	51.7	81.0	2.3
2020	23.1	16.1	119.4	200.2	134.2	191.0	372.4	260.9	163.2	64.9	24.9	25.2
Total	66.2	257.3	458.4	1069.2	1561.1	2209.1	2499.5	2388.4	1802.4	543.1	286.7	59.7

Source: Southern Nation, Nationality and Peoples' Regional State Meteorological Services Agency (2021)

Appendix Table 2: Mean monthly and annual maximum temperature (^{0}C) at the study area (2011-2020)

	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	24.3	24.9	24.7	27.5	27.1	24.3	23.1	21.7	21.7	25.1	25.3	25.5
2012	25.6	28.0	28.0	27.0	27.5	23.0	21.0	21.4	22.2	25.2	25.2	25.3
2013	26.2	27.5	27.2	27.0	24.9	23.7	21.9	21.9	22.4	23.7	24.6	25.0
2014	26.5	26.1	26.6	26.5	24.8	25.0	22.7	21.3	22.0	24.0	24.6	24.9
2015	25.9	27.5	28.3	28.1	25.3	23.0	22.8	22.4	23.0	25.5	25.5	25.0
2016	26.0	26.5	26.4	25.5	27.3	23.3	22.2	22.0	22.9	25.4	25.4	25.3
2017	25.3	27.2	26.7	27.3	25.3	22.7	21.5	21.4	24.1	24.7	24.7	24.8
2018	25.7	26.6	27.3	25.1	25.8	22.4	21.4	21.7	23.5	25.1	24.4	25.1
2019	27.0	27.5	27.6	25.3	25.7	22.7	21.1	21.3	22.2	24.5	24.7	24.9
2020	26.0	27.0	26.2	26.0	24.7	23.0	21.0	21.3	22.3	24.4	25.3	25.5
Total	258.5	268.9	269.0	265.3	258.4	233.2	218.8	216.3	226.3	247.5	249.7	251.2

Source: Southern Nation, Nationality and Peoples' Regional State Meteorological Services Agency (2021)

Appendix Table 3: Mean monthly and annual minimum temperature (^{0}C) at the study area (2011-2020)

	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	8.6	7.8	8.0	12.7	11.7	13.1	12.0	11.9	11.6	9.7	8.6	6.3
2012	8.4	6.8	9.6	12.9	11.8	12.3	12.5	12.5	11.9	9.0	8.8	6.9
2013	7.9	9.1	11.9	12.1	12.0	12.5	12.3	12.5	11.5	9.7	8.4	6.6
2014	7.1	10.3	10.2	10.8	11.5	11.3	12.1	11.7	11.9	10.7	9.0	7.7
2015	6.7	9.1	9.7	10.7	12.1	13.0	12.8	12.5	11.9	9.9	9.0	9.3
2016	6.5	9.7	10.2	10.6	11.9	12.3	12.5	12.7	12.0	9.1	9.2	7.7
2017	7.1	9.3	11.1	11.8	12.0	12.7	12.1	12.1	11.5	9.8	9.7	8.7
2018	7.8	9.8	10.9	12.6	12.4	22.4	12.3	12.3	11.3	9.4	8.9	7.0
2019	5.5	9.2	10.8	12.8	11.0	13.5	12.6	12.5	12.5	9.8	10.0	8.8
2020	8.5	10.4	12.6	12.3	12.7	12.9	13.1	13.2	12.0	9.0	7.7	6.2
Total	74.03	91.5	105.0	119.3	118.9	136.0	124.3	123.9	118.1	96.0	89.3	75.3

Source: Southern Nation, Nationality and Peoples' Regional State Meteorological Services Agency (2021)

Appendix Table 4: Mean square values of phenology parameter of potato as influenced by varieties and blended NPSB fertilizer

Source of variation	Degrees of freedom	Days to Emergency	Days to Flowering	Days to Maturity
Replication	2	0.69	24.08	24.36
Varieties	2	27.69**	456.33**	259.19***
NPSB	3	9.44ns	341.58**	260.47***
Variety*NPSB	6	5.66ns	15.22ns	33.86**
Error	22	4.03	48.36	7.76

Where: *** = Very highly significant; ** = highly significant; * = significant; and ns = non-significant

Appendix Table 5: Mean square values of plant height, number of main stem per hill, number of tuber per hill and tuber yield per hill of potato as influenced by varieties and blended NPSB fertilizer

Source of variation	Degrees of freedom	Plant height	No of main stem per hill	Number of tuber per hill	Tuber yield per hill
Replication	2	7.36	0.11	0.62	0.0017
Varieties	2	489.42***	15.61***	18.71***	0.810***
NPSB	3	578.76***	10.69***	38.42***	0.72***
Variety*NPSB	6	53.76*	1.13*	1.96*	0.054**
Error	22	20.14	0.44	0.66	0.0128

Where: *** = Very highly significant; ** = highly significant; and * = significant

Appendix Table 6: Mean square values of small tuber sized, medium tuber sized and large tuber sized yield of potato as influenced by varieties and blended NPSB fertilizer

Source of variation	Degrees of freedom	Small tuber size	Medium tuber size	Large tuber size
Replication	2	0.46	5.15	3.56
Varieties	2	11.7***	45.28***	262.57***
NPSB	3	6.73***	79.41***	168.36***
Variety*NPSB	6	1.16ns	3.33ns	17.61***
Error	22	0.62	1.58	2.69

Where: *** = Very highly significant; and ns = non-significant

Appendix Table 7: Mean square values of marketable tuber yield, unmarketable tuber yield and total tuber yield of potato as influenced by varieties and blended NPSB fertilizer

Source of variation	Degrees of freedom	Marketable tuber yield	Unmarketable tuber yield	Total tuber yield
Replication	2	10.20	0.155	12.04
Varieties	2	232.74***	0.415*	215.34***
NPSB	3	384.87***	1.33***	341.48***
Variety*NPSB	6	24.027*	0.073ns	24.85*
Error	22	7.12	0.11	7.46

Where: *** = Very highly significant; * = significant; and ns = non-significant

Appendix Table 8: Mean square values of quality parameters of potato as influenced by varieties and blended NPSB fertilizer

Source of variation	Degrees of freedom	Specific gravity of tuber	Tuber dry matter content	Tuber starch content
Replication	2	0.000045	1.74	1.81
Varieties	2	0.00066^{***}	34.69^{***}	26.37^{***}
NPSB	3	0.00036^{**}	18.46^{***}	14.33^{**}
Variety*NPSB	6	0.000044^{ns}	4.16^{*}	1.76^{ns}
Error	22	0.000052	1.57	2.066

Where: *** = Very highly significant; ** = highly significant; * = significant; and ns = non-significant