EFFECT OF BLENDED NPS AND ZINC FERTILIZER RATES ON GROWTH, YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT DEBRE BERHAN, NORTH SHEWA, ETHIOPIA

MSc. THESIS

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DEBRE BERHAN, ETHIOPIA

EFFECT OF BLENDED NPS AND ZINC FERTILIZER RATES ON GROWTH, YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT DEBRE BERHAN, NORTH SHEWA, ETHIOPIA.

A Thesis Submitted to the Department of Horticulture

College of Agriculture and Natural Resource Sciences, College of Graduate Studies, Debre Berhan University

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

Workiye Hailemeskel

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Debre Berhan, Ethiopia

APPROVAL SHEET – I

This is to certify that the thesis entitled: **EFFECT OF BLENDED NPS AND ZINC FERTILIZER RATES ON GROWTH, YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum Tuberosum* L.) AT DEBRE BERHAN, NORTH SHEWA, ETHIOPIA** submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Horticulture of the Graduate Program of the Department of Horticulture, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by Workiye Hailemeskel Id. No DBU/1400520, under my supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it to be accepted as fulfilling the thesis requirements.

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Co- Advisor	Signature	Date

COLLEGE OF GRADUATE STUDIES, COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES, DEBRE BERHAN UNIVERSITY

APPROVAL SHEET – II

We, the undersigned members of the board of the examiners of the final open defense by Workiye Hailemeskel have read and evaluated her thesis entitled **EFFECT OF BLENDED NPS AND ZINC FERTILIZER RATES ON GROWTH, YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT DEBRE BERHAN, NORTH SHEWA, ETHIOPIA**, and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Horticulture.

Name of chairman	Signature	Date
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Name of Major Advisor	Signature	Date
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Name of Internal Examiner	Signature	Date
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Name of External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the department graduate committee (DGC) of the candidate’s major department.

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DEDICATION

I dedicated this thesis to my families their affection and consistent care in the success of my life.

STATEMENT OF THE AUTHOR

First, I declare that this Thesis is my work and all sources of materials used for this Thesis have been duly acknowledged. I submit this thesis to Debre Berhan University in partial fulfillment of the requirements for the Degree of Master of Science in Horticulture. The thesis is deposited at the library of the University to be made available to borrowers for reference. I solemnly declare that I have not so far submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
DAP	Di-ammonium Phosphate
DMRT	Duncan's Multiple Range Test
EARO	Ethiopian Agricultural Research Organization
EthioSIS	Ethiopian Soil Information System
FAOSTAT	Food and Agriculture Organization of the United Nation Statistics
IDM	Integrated diseases management
M.a.s.l	meters above sea level
MoA	Ministry of Agriculture
MoANR	Ministry of Agriculture and Natural Resource
NPS	Nitrogen, Phosphorous, Sulphur
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SNNPR	South Nation Nationality and People Representative

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Workiye Hailemeskel

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ABSTRACT

Potato (Solanum tuberosum L.*) is an important leading tuber crop for food and nutrition security as well as cash crop for smallholder farmers in Ethiopia. However, the yield of the crop is low at national as well as regional level due several factors such as inappropriate agronomic practices, disease and pests, lack of good quality seeds among which low soil fertility and poor fertilizer management practice applied by growers. A field experiment was carried out during the main cropping season at Debre Berhan University College of agriculture and natural resource science research site. The field experiment was conducted with the objective of evaluating the effects of NPS fertilizer and zinc on the growth, yield, yield components and quality of potato. The treatments consisted of four levels of NPS (0, 90, 180 and 270 kg ha^{-1}) fertilizer and four levels of zinc (0, 225, 450 and 675 ppm) and an improved potato variety called 'Belete' was used as a test crop. The experiment was laid down in a Randomized Complete Block Design (RCBD) in a 4x4 factorial arrangement and replicated three times. Results of the experiment indicated that the main effects of NPS and zinc fertilizers as well as the interaction effects significantly affected plant height, main stem number, number of branch, average tuber weight, marketable tuber number per hill, total tuber number per hill, marketable tuber yield (t ha^{-1}), total tuber yield (t ha^{-1}), tuber dry matter, specific gravity and tuber starch content. The highest marketable tuber yield (42.45 t ha^{-1}) and total tuber yield (46.06 t ha^{-1}) were obtained from the application of 180 kg ha^{-1} NPS and 450 ppm zinc. The combined application of NPS and zinc fertilizer at the rate of 180 kg ha^{-1} NPS and 450 ppm zinc increased marketable tuber yield by 161.71% and total tuber yield by 110.22% over the control treatment. On the other hand, the lowest marketable tuber yield (16.22 t ha^{-1}) and total tuber yield (21.91 t ha^{-1}) was recorded from the control treatment. The combined application of 180 kg ha^{-1} NPS and 450 ppm Zn fertilizer level gave the maximum net benefit (Birr 1,122,300 ha^{-1}) with an acceptable marginal rate of return (3304.35%). Hence, for economical potato production in the study area and similar agro-ecologies, it is advisable to apply 180 kg NPS ha^{-1}and 450 ppm Zn fertilizer.*

Keywords: Dry matter content, Marginal rate of return, Zinc, Marketable tuber yield, Net benefit

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is a key global food crop and the world's most important vegetable crop in terms of production and consumption (Kumar *et al*., 2020). After wheat, rice, and maize, potato ranks fourth most commercially important food crop (Mah *et al*., 2021). Potato is a good source of energy, low cost, high nutritional value, and high productivity, helping to alleviate global food shortages and ensure food security for the world's rising population (CIP, 2017; Zhang *et al*., 2018). However, demand for both food and energy is increasing, and this trend is expected to continue as the world population and average income rise (Lobell *et al*., 2009). It contains approximately 79% water, 18% starch as a safe source of energy, 2% protein and 1% vitamins, including vitamin C, minerals including calcium and magnesium and many trace elements (Ahmad *et al.,* 2011). The potato has better ability to furnish a high output of high-quality product per unit input with a shorter crop cycle (generally less than 120 days) as compared to major food grain crops like maize (Hirpa *et al.,* 2010). As a result, the crop is appreciated as a respectable source of nutrient food and cash by a large number of food insecure smallholder farmers and pastoralists in Ethiopia (Haverkort *et al.,* 2012).

The potato has become an important crop in many parts of Ethiopia since its introduction in 1858 by the German botanist Schimper (Pankhurst, 1964). It ranks first among root and tuber crops in Ethiopia, both in volume of production and consumption followed by Cassava, Sweet potato and Yam where smallholder farmers are the major producers as food and cash crop (CSA, 2019). It is currently the world's production is about 376 million tons from 18.1 million hectares of land with an average yield of 20.7 t ha^{-1} (FAOSTAT, 2021). China is the biggest producer of potatoes worldwide (99,122,420) tonnes and Africa`s potato production is about 26.5 million tonnes with average yield of 15.04 t/ha (FAO, 2019). In 2021, Ethiopia produced about 1.1 million tons of potatoes with an average yield of 13.27 t ha^{-1} (FAOSTAT, 2021).

The gap between the potential yield and actual average national yield per unit area of land could be due to unavailability and high price of quality seed tubers, lack of improved varieties, unbalanced fertilization, low use of organic manures, and low market price at the time of harvesting, diseases and post-harvest losses (Tesfaye, 2011). The absence of recommended fertilizer types and rates best fit to the specific area and production system is also production constraint of potato (Haverkort *et al*., 2012). It is imperative to increase the productivity alone with desirable attributes through production management practices and application of other sources of nutrients beyond the blanket recommendation of urea and DAP, especially those that contain potassium, sulfur and other micro nutrients (EthioSIS, 2015).

The application of inorganic NPS blended fertilizers has the main advantages to the farmers from which nutrients are supplied in ratios to suit the demands of particular soils and crops (Roy *et al.,* 2006). Increasing the rates of NPS fertilizers increased plant height, stem number, leaf area index, days to flowering, days to maturity, average tuber number per hill, average tuber weight, marketable tuber yield and total tuber yield (Minwyelet *et al.,* 2017; Arega, 2018 and Melkamu *et al.,* 2018).

Zinc is considered as the most important micronutrient for potato and low recovery of applied Zn is the main limitation in enhancing the yield of potato (Singh *et al*., 2014). Zinc is a micronutrient essential to plant and has a major role in the development of plant growth and productivity. It is an important plant nutrient and a deficiency of which not only confines crop production (Cakmak, 2008), but also affects nutritional value and human health. It also a vital essential nutrient for improving crop yield and productivity (White and Broadley, 2011) and provides nutrition security. Zn helps to increase the rate of photosynthesis and the translocation of photosynthates leading to increased size and number of tubers. Zinc (Zn) contributes towards synthesis of growth promoters like auxins (IAA-Indole Acetic Acid) and gibberellins while reduces the level of inhibitors like abscisic acid (ABA) to improve the IAA/ ABA and cytokinin / ABA ratio, which induces the formation and growth of stolon resulting the increase in number of tubers, mean tubers weight and finally high performance of potato crop is due to utilization of Zn fertilizers in potato (Gangele *et al*., 2020). Generally, foliar application of micronutrient is very fast method of providing the required element to plants as compared to absorption through plant roots, because nutrients are absorbed quickly (Hashemymajd *et al*., 1998).

Potato requires a variety of plant nutrients for growth and development. Nitrogen, phosphorus, potassium and sulfur are the most important among the elements that are essential to potato (Israel *et al*., 2012). In this regard, various researches have been conducted throughout Ethiopia with the objectives of determining the fertilizer requirements of potato (Israel *et al*., 2012). Potato is a heavy feeder requiring large quantities of fertilizers to produce highest marketable tuber yield and total tuber yield. On the other hand, low soil fertility is one of the limiting factors to sustain potato production and productivity in Ethiopia as Ethiopian soils are very diverse in terms of inherent and dynamic soil quality (Zelalem *et al*., 2009). Inappropriate agronomic practices and shortage of improved potato varieties are also the other major constraints of potato production in the country (Alemayehu *et al.*, 2015). Fertilizer recommendations made based on preliminary studies vary across diverse agro ecologies in the country. Economically feasible fertilizer amount varies with soil type, fertility status, moisture amount, climatic variables, variety, crop rotation and crop management practices (Berihun and Woldegiogis, 2012). In this regard, Hailu (2014) reported that Ethiopian soils lack most of the macro and micronutrients that are required to sustain optimal growth and development of crops including potato.

In most part of Ethiopia, the sources of plant nutrients for agriculture over the past five decades have been limited to urea and Diammonium Phosphate (DAP) fertilizers which contain only nitrogen and phosphorus that may not satisfy the nutrient requirements of crops. To alleviate this problem, the Ministry of Agriculture of Ethiopia has introduced a blended fertilizer which contains nitrogen, phosphorous and sulfur (NPS) with the ratio of 19% N, 38% P_2O_5 and 7% S. This fertilizer has been distributed in Ethiopian crop production system (Ministry of Agriculture and Natural Resource (MoANR, 2013). However, the situation is challenging for the smallholder farmers to apply the recommended rate of NPS fertilizer for the production of potato. In addition to this, the application and rate of micro-nutrient especially Zinc is not studied very well in the study area, and also the farmers do not have the awareness about the importance of micro- nutrient for crop production. For sustainable production of potato, micronutrient especially zinc management is very important. However, no data is available regarding foliar application of zinc, and also the combined application of NPS and Zinc fertilizers in potato in the Debre Berhan district. Therefore, this research was undertaken with the following objectives:

1.1. Objectives

General objective

- To evaluate the effect of NPS and Zinc fertilizers on growth, yield, yield components and quality of potato (*solanum tuberosum* L.).

Specific objectives

- To evaluate the effect of NPS fertilizer on growth, yield, yield components and quality of potato.
- To evaluate the effect of Zinc fertilizer on growth, yield, yield components and quality of potato
- To evaluate the interaction effect of NPS and Zinc on growth, yield, yield components and quality of potato.
- To determine the economically feasible rates of NPS and Zinc fertilizers for higher yield and quality of potato.

2. LITERATURE REVIEW

2.1. Botany of potato

The cultivated potato belongs to the family Solanaceae, genus Solanum, and accommodated in series Tuberosa (van den Berg and Jacobs, 2007). The plant bears two kinds of stems, the above ground base that supports the leaves and flowers and the underground one whose terminal portion swells to form the tubers as it accumulates starch and carbohydrates from photosynthesis in leaves (Margaret *et al.*, 2007;Anonymous, 2013).

Branching may occur at any node, but branching is most common at the stem of the plant. Some branches arise from underground nodes on the main stem. Without disturbing the soil, it is difficult to tell these from stems that have originated from separate eyes of the seed tuber. Other auxiliary branches arise from nodes just above the soil. The extent of axillary branching, both sympodial and basal, is of essential importance in determining yield potential (Ewing, 1997). Leaves are pinnate with a single terminal leaflet and three or four pairs of large, ovoid leaflets with smaller ones in between (Struik, 2007).

Flower initiation generally occurs before tuber initiation and takes place a few weeks after emergence. In this sense, potato is a determinate plant. The clusters bear white, pink, crimson, bluish, or purple blooms with yellow stamens. Flower bud abortion may take place at a very early phase of development, but in any event, the apical growth of the main stem ceases with the shaping of the flower buds. The cessation of development of the main shoot axis may not be obvious because sympodial growth of one or more auxiliary branch just under the apex permits further extension above the flower cluster (Alemkinders and Struik, 1994). The fruits are small inedible berries and contain poisonous alkaloids (Rice *et al.*, 1990). The fruits are spherical to ovoid berries, about 1-4 cm in diameter. They are green or green tinged with white or purple spots or bands when ripe (Spooner and Salas, 2006).

The potato has a relatively shallow, fibrous root system with the majority of the roots in the surface 30 cm depth (Onder *et al.*, 2005).The root system grows rapidly during early development and achieves maximum development by mid-season. Thereafter, root length, density and root mass decrease as the plant grows. Rooting depths of 1.2 m or more have been reported for potato under favorable soil conditions (Tanner *et al*., 1982).

2.2. Origin, taxonomy, and distribution of potato

Potato (*Solanum tuberosum* L.) first originated from the Lake Titicaca region in Peru and Bolivia which are high-elevation areas of South America (Hoops and Plaisted, 1987). Then potato crop has successfully spread across Europe, Asia, Oceania, and Africa since the discovery of the Americas by European explorers. It is grown in nearly 160 countries in the world (FAOSTAT, 2021).

The potato is a member of the *Solanaceae* family, having a standard set of 12 chromosomes (x=12). It belongs to the genus *Solanum*. *Solanum tuberosum* L., which is a tetraploid (4n=48) genome and is the most widely grown species (Rosa *et al*., 2010). There are about 5000 varieties of potatoes in the world today (Zaheer and Akht, 2016). *Solanum tuberosum* L. is a perennial herbaceous plant in the family *Solanaceae*, and it is grown for its edible tubers (Burkill, 1995). Depending on the variety, the tuber's color can range from red to purple to yellow. Matured potato plants are about 1 meter in height and are grown as annuals that survive only one growing season (Gusha, 2014).

In the tropics, potato grown in the cool highlands and the subtropics in the cool season, or at mid-elevations. In the temperate zone, it is a lowland crop (Hijmans, 2001). The distribution area of the potato is highly skewed to the northern hemisphere, particularly to the temperate zone in Europe, where its share is high at 51% of the total global area. In Africa potato production has more than doubled, accounting for 70% of that growth concentrated in Eastern Africa (Hijmans, 2001). Schimper, a German botanist, brought the potato to Ethiopia in 1858 (Pankhurst, 1964). It has served as a food and income crop for small-scale farmers since then. Potato is widely distributed in different parts of the country including, Oromia, Amhara, SNNPR, and Tigray. Oromia is the major potato-producing region because of its ecological suitability and market outlet (Bezabih and Mengistu, 2011).

2.3. Ecological requirements of potato

2.3.1. Climate requirement of potato

Potato is grown in temperate, subtropical, and tropical climates, and it is considered as "cool weather crop," with temperature being the key limiting factor in production. The best yields are attained when mean daily temperatures are between 18 and 20 degrees Celsius (CIP, 2008). Potatoes are grown mostly at high altitudes between 1,500 and 3,000 meters above sea level, with annual rainfall ranging from 600 to 1200 mm throughout the growing season, and water supply for the potato crop should be consistent to maximize yields and tuber quality (FAO, 2009). Since potato is a shallow-rooted crop, it is susceptible to moisture stress, especially after tuber initiation (Nyawade *et al.,* 2018). Uneven tuber bulking, tuber malformation, and tuber growth fissures will lead to changes in soil moisture condition inside the ridges, resulting in reduced yields (Polgar *et al.,* 2017).

2.3.2. Soil requirement of potato

Potato may be grown in a variety of soils, but the best are medium textured loamy soils because it holds plenty of moisture but also drains well so that sufficient air can reach the roots, tuber development with minimal root disease infestation, pH 5.5 to 7.0, and low salinity (Gebremedihin *et al.,* 2008). However, potatoes are commonly cultivated in soil pH ranges of 4.5 to 8.5, which have a significant influence on the availability of certain nutrients (CIP, 2008). The optimal soil type in Ethiopia is deep and well-drained, with a silt loam or sandy loam texture that is somewhat acidic and has a loose and friable structure with a pH in the range of 4.8-6.0 (EARO, 2004).

2.4. Importance of potato in Ethiopia

Potatoes play a critical role in ensuring food security for the ever-growing world population (Devaux *et al*., 2021). More than a billion people worldwide rely on potatoes as a staple food to meet their energy and nutritional needs. In rural areas of developing countries, potato cultivation, and post-harvest activities are key sources of employment and income. It can be utilized as a food security crop, a cash crop, animal feed, and a starch supply for a variety of industrial applications (FAO, 2008). Potatoes are eaten in a variety of ways, including boiled, fried, and processed items such as chips, French fries, flakes, powder, and so on, and are enjoyed by people of all generations and continents (Pandey *et al*., 2009). Furthermore, the protein level of potatoes is comparable to that of cereals and is far higher than that of other roots and tubers. In addition, the potato is low in fat and high in a variety of micronutrients (Lutaladio and Castaldi, 2009).

In developing countries, potatoes are essential to the life of hundreds of millions of people. Potato cultivation is expanding rapidly in the developing world, where the potato’s high nutrient content, ability to adapt to marginal environments, relative ease of cultivation, and low cost and high productivity are causes that make potatoes one of the principal and most important sources of food and income for poor citizens of developing countries around the world (CIP, 2017). The Ethiopian government has also regarded potatoes as a key crop to boost food security and economic advantages to society because potatoes have a high potential to provide cheap and high-quality food within a relatively short period (Helen, 2016).

In many human communities, the potato (*Solanum tuberosum* L.) is an integral part of the diet and a source of many vital nutrients. Potato is about 80% water and 20% of dry matter content in newly harvested tubers. The main component of potato (*Solanum tuberosum* L.*)* is starch; however, it also contains small amounts of protein and alkaline salts. They are essentially fat- and cholesterol-free complex carbohydrates in the form of sugars. Numerous vitamins are contained in potato (*Solanum tuberosum* L.) including beta-carotene, vitamin C, vitamin A, vitamin B1, B2, B6, and folic acid. It also contains trace amounts of protein, amino acids, and nicotinic acid (Navarre *et al.*, 2009; Belay and Chibuzo, 2021).

2.5. Potato production opportunities and challenges in Ethiopia

2.5.1. Opportunities of potato production in Ethiopia

Ethiopia has highest potential for potato production of any country in Africa (MoA, 2012). This might be due to a high potential to expand the cultivation area of the potato crop, as about 70% of the country's available agricultural land is located at an altitude of 1800-2500 meters above sea level and receives an annual rainfall of more than 600 mm, which is potentially suitable for potato production (Gebremedhin *et al.*, 2008). Since potato is grown from mid altitudes to very high mountain tops, and from humid to dry areas in the country, improvements in productivity will require the development of varieties best adapted to a wide range of environments (Semagn *et al.*, 2015). As a highland country located in the tropics, Ethiopia has very conducive edaphic and climatic conditions for the production of high quality seed potato (Bezabih and Hadera, 2007). Availability of improved technologies eg. Varieties, Management, IDM, etc., growing interests of public and non-governmental organizations in potato seed, increased farmer knowledge of potato seed production and management, high demand for quality seed, and high returns, good networking for intra-regional nuclear seed exchange , strong support of the International Potato center (CIP) and other stakeholders, conducive policy framework , high irrigation potential and conducive market proximity and niche and high yield per unit area as compared to other crops (Abebe, 2019).

2.5.2. Challenges of potato production in Ethiopia

The low acreage and productivity of potato in Ethiopia are attributed to many factors. The major ones are lack of well adapted and high-yielding cultivars, unavailability and high cost of seed tubers, inappropriate agronomic practices, and lack of marketing and suitable postharvest management facilities, pests and disease (Tekalign, 2005; Gebremedhin *et al.,* 2008 and Gildemacher *et al.,* 2009). Lack of varieties with stable and high yield potential, lack of good quality seeds, disease and pest problems, drought and seed dormancy to fit the local cropping calendar, lack of improved characterizations are very important limitations to potato production by smallholder farmers in sub-Saharan-Africa (Fuglie, 2007). According to, Tekalign (2005) 98.7% of the seed tubers required in Ethiopia are supplied from the local varieties. The seed tubers supplied by this system have poor sanitary, physiological, physical and genetic qualities (Tekalign, 2005).

The yield gap between attainable and potential yield of potato in Ethiopia is very high. In Ethiopia on bacterial wilt finds out that disease are one of the most important factors that contributes to this high yield gap in the country (Aliye *et al.*, 2008). The contribution of diseases to the gap between the production potential and the current average national production takes a large part since potato crop is susceptible to a number of diseases including late blight, viruses and bacteria wilt (Aliye *et al.*, 2008). This same study indicated that mid altitude areas of the country around Shashamene, Bako, Jima and Rift Valley are most affected by bacterial wilt. Sub-optimal agronomic practices are also the other most important factor contributing to this potato yield gap (Gebre and Gebremedhin, 2001). Furthermore, the use of local varieties is one and the most important factors which contribute to the low yield of potato in Ethiopia. This is because; the local varieties are susceptible to late blight and of course low yield potential (Getachew and Mela, 2000).

2.6. Effect of mineral fertilizers on growth and yield of potato

In the past years, mineral fertilizer was advocated for crop production to ameliorate low inherent fertility of soils in the tropics. However, currently it is well recognized that the use of mineral fertilizer has not been helpful in intensive agriculture because it is often associated with reduced crop yield, soil acidity and nutrient imbalance (Kumar *et al*., 2013). Appropriate mineral fertilizer application, especially nitrogen and phosphorus are required to correct the nutrient imbalance in infertile soils (Peter *et al*., 2015). Potatoes require high quantity of nutrients in order to form abundant vegetative mass and high quantity tubers per unit area

(White *et al.*, 2007). Moreover, potatoes require high amounts of fertilizer due to the characteristics of shallow and inefficient rooting system (Dechassa *et al.*, 2003). Potatoes respond to an ample soil moisture supply with an increase in yield and quality (Dolores *et al.*, 2009). A rainfall ranging between 500 and 750 mm with even distribution during the growing period is generally necessary for optimum growth (MoA, 2011). Potatoes have relatively shallow root zone and lower tolerance for water stress compared to other crops, therefore irrigation may be required where rainfall is limited (Makani *et al*., 2013). Increasing the rate of nitrogen increase total tuber yield/plot average tuber weight, marketable tuber weight, unmarketable tuber weight, total tuber number/ plant and small tuber size (Fayera, 2017). Increasing the rate of nitrogen up to 375 kg ha^{-1} increases the plant height of potatoes (Sanjana *et al*., 2014). Potato were given 0, 125, 250 or 375 kg N ha^{-1} and resulted significant increase in plant height, stem number $plant^{-1}$ (Anabousi *et al*., 1997).

2.6.1. Effect of nitrogen fertilizer on growth and yield of potato

Nitrogen is a very important nutrient in potato production. Numerous substances, including proteins, chlorophyll, nucleotides, alkaloids, enzymes, hormones, and vitamins, which are crucial for the growth processes of plants, contain nitrogen as an essential component (Brady and Weil, 2008). Nitrogen fertilizer supply and rate notably interact in all vegetative growth traits as expressed by using plant length, leaf number per plant, leaf area per plant, leaf chlorophyll content, and plant fresh and dry weights (Nuru and Tenalem, 2019). Plant uptake nitrogen both in the cationic (NH_4^+) and/or the anionic (NO_3^-) form. Nitrogen fertilizer increases the nitrogen intake and this increase causes a positive effect on chlorophyll concentration, photosynthetic rate, plant height, the entire number of leaves and dry matter accumulation (Israel *et al.,* 2012). Nitrogen in the presence of adequate phosphorus stimulates canopy growth, leaves and branches. This is through the production of excess leaves and branches, an extension of leaf area duration and expansion of leaf area (Muthoni and Kabira, 2011). Nitrogen is essential for increasing plant height, leaf area index, shoot dry matter, and tuber yield (Zelalem *et al*., 2009). Increasing the rate of nitrogen from 0 to 138 N kg ha^{-1} increased the plant height of potatoes from 43.15 cm to 49.82cm (Workat, 2020). Nitrogen fertilizer plays a significant role in production of stem and axillary branches (Moorby, 1967).

Nitrogen is the nutrient that has the greatest impact on tuber yield and quality (Mokrani *et al*., 2018). Total tuber yield, marketable tuber yield, and average tuber weight will all increase with a rising nitrogen utility rate (Nuru and Tenalem, 2019). Nitrogen is crucial for the development of tuber size (Zelalem *et al*., 2009). Increasing the rate of nitrogen from 100 to 150 kg ha^{-1} increases average tuber weight and total dry matter yield (Fayera, 2017). Growing nitrogen application up to 165 kg ha^{-1} enhances total tuber number, marketable tuber number, total tuber yield, marketable tuber yield, and average tuber weight (Alemayehu *et al*., 2015). Application of 165 kg N/ha increased shoot dry weight from 52.75 to 72.25 by 19.5 g/hill compared to control (Israel *et al*., 2012). The greatest marketable yield was also produced by the nitrogen utility at rates of 110 and 165 kg ha^{-1}. N fertilization had been reported to increase the average fresh tuber, plant height, leaf number and tuber weight per plant (Kandil *et al.*, 2011).

The application of 165 kg N ha^{-1} significantly increased the days to flowering, days to physiological maturity, amount of total tuber yield, amount of marketable tubers, amount of total tuber number, and average tuber weight (Israel *et al*., 2012). The application of 207 kg N ha^{-1} increased total tuber yield by 119%, tuber number by 34%, and average tuber weight by 82% compared to the control (Zelalem *et al*., 2009). Application of 150 kg N ha^{-1} produced the highest overall tuber yield (40.17 t ha^{-1}) compared to other N rates (50 and 100 kg ha^{-1}) while the lowest value (17.28 t ha^{-1}) was obtained from control (Frezgi, 2007).

2.6.2. Effect of phosphorus fertilizer on growth and yield of potato

Phosphorus is a second limiting nutrient in potato growth and important in cells of living organisms (Hopkins *et al*., 2014; Mikkelsen *et al*., 2014; Rosen *et al*., 2014). It is an essential macronutrient for nucleic acid synthesis, membrane build up and stability, energy metabolism, and many other critical physiological and biological processes during plant growth and development (Lambers *et al*., 2015). Plant uptake phosphorus in the form of $H_2PO_4^-$ and HPO_4^- (Tisdale *et al.*, 1995). It is a nutrient that should be available in adequate quantities from the early growth stages to maintain a high photosynthetic rate during tuber bulking (Hue *et al*., 2010; McCollum, 1978b and Grant *et al.*, 2001). Phosphorus nutrition also enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, root growth, particularly the development of lateral roots and fibrous rootlets (Brady and Weil, 2008). For potatoes, phosphorus is an essential element. It plays a significant role in physiological and biochemical reactions such as photosynthesis, and the conversion of sugar into starch (Taheri *et al*., 2011). P also functions as a chemical building block for a variety of coenzymes, phospholipids, and molecules of DNA and RNA (Rosen *et al*., 2014). Potato has low P efficiency owing to its low P use efficiency and little ability to take it up at lower P levels

(Dechasa *et al*., 2003). Economically, the application of an appropriate rate of phosphorous significantly increased plant height, marketable tuber number and yield, and tuber size of potato (Zelalem *et al*., 2009). P also has a significant impact on the setting of potato tubers, especially in the early growth states but also at later growth stages where P enhances tuber maturity (Hopkins, 2014; Rosen *et al*., 2014). Potato tuber yield increased with increasing rates of P. Potato development and maturity are suppressed and delayed by the P deficiency (Hopkins *et al*., 2019). Total tuber production grew linearly with increasing P fertilizer rates at 0, 34, 67, and 100 kg ha^{-1} P_2O_5 (Mohr and Tomasiewicz, 2008). Increasing the rate of P from 0 to 138 kg P significantly increased tuber number $plant^{-1}$ from 6.4 to 7.9 (Firew, 2016). Increasing the rates of P increased the number of tubers set per plant (Israel *et al*., 2012) and (Zelalem *et al*., 2009). In Ethiopia national phosphorus recommendation for potatoes is 90 kg ha^{-1} P_2O_5 (Berga *et al*., 1994). The application of 90 kg ha^{-1} P_2O_5 was required for the optimum yield of potato crops (Getu, 1998). An increase in phosphorus fertilizer revealed a significant contribution to total tuber yield and advanced to get larger average tuber weight and size (Israel *et al*., 2012).

2.6.3 Effect of sulfur fertilizer on growth and yield of potato

Sulfur is one of the most vital nutrients, playing a significant role in plant metabolism together with nitrogen, phosphorus, potassium, and magnesium (Barczak and Nowak, 2014). Sulfur can be a nutrient that restricts plant production and quality because it is necessary for a variety of cellular metabolites (Koprivova and Kopriva, 2016). Sulfur has numerous functions in plant growth and development, ranging from being a structural constituent of macro-biomolecules to influencing several physiological processes and abiotic stress tolerance. Sulfur can help increase crop yield, productivity, and quality in the face of the rising demand for high-quality vegetable diets (Zenda *et al*., 2021). Crop growth and yield responses to S application have been recorded for crops that, without enough S, cannot attain their full potential in terms of yield, quality, or protein content (Sahota, 2005). Application of sulfur-containing fertilizers like NPS improves the availability of plant nutrients like P, Fe, Mn, and Zn, by amending the soil pH which may increase yields of vegetable crops like potatoes (Marschner, 1995). Rahman *et al*. (2019) reported that the highest tuber yield of 40.07 t ha^{-1} was recorded by application of 100% recommended dose (45 kg ha^{-1}) of sulfur and the lowest tuber yield 25.16 t ha^{-1} recorded from control. The yield promotion by S is a result of the effect of this nutrient on nitrogen metabolism and the synthesis of proteins and chlorophyll. The application of 45 kg ha^{-1} sulfur gave the highest tuber yield, large and medium tuber size, dry matter content, specific gravity, sugar content, and starch content (Sharma *et al*., 2011). Similarly, S levels showed significant influence on grade wise tuber yield (Sharma, 2015).

Sulfur is being known in view of its function in improving crop quality and balance of anions in agricultural crops including potatoes (Tandon, 1991). Sulfur fertilization has positively changed the tuber yield of potato while decreased the content of dry mass (Cultus, 2013). It also enhances starch synthesis in tubers and it is a constituent of proteins and many enzymes (Lalitha *et al.,* 2002). It increases the resistance of potatoes to environmental stress and acts as an important part in protecting the plants from pests and diseases (Klikocka, 2005). Sulfur fertilizer contributed to a significant increment of potato tuber yield through enlarging tuber weight per plant (Barczak and Nowak, 2015). Also, S has a role in promoting growth (El-Shafe and El-Gamaily, 2002) and better partitioning of photosynthesis in the shoot and tubers (Sud and Sharma, 2002).

2.6.4. Effect of blended NPS fertilizer rates on growth and yield of potato

Soil fertility status, type, amount and time of application have great influence on yield and quality of potato (Westermann, 2005). The application of inorganic NPS blended fertilizers has the main advantages to the farmers from which nutrients are supplied in ratios to suit the demands of particular soils and crops (Roy *et al*., 2006). Increasing rates of NPS fertilizer may promote the vegetative phase of potato plants that may in turn prolong flowering and maturity of the potato plant. This might be attributed from the increased N uptake from the applied NPS fertilizer that contributes to excessive haulm development and in turn prolonged days required to attain 50% flowering and 90% maturity (Minwyelet, 2017).

Increasing the rates of NPS fertilizers increased plant height, stem number, leaf area index, days to flowering, days to maturity, average tuber number per hill, average tuber weight, marketable tuber yield and total tuber yield (Melikamu *et al*., 2018). Various researchers reported the beneficial effects of the application of sulfur-containing fertilizers like NPS on growth, yield and yield parameters as well as the quality of potato (Choudhary, 2013). NPS is critical for optimizing potato growth, yield and quality (Miller and Rosen, 2005). The increased potato plant height by application of NPS may be attributed by physiological stem elongation effect of N which is also observed by other authors (Kinde and Asfaw, 2016).

Plant height of potato was highly significantly influenced by NPS fertilizer rates (Lakew and Fanuel, 2021). Application of NPS fertilizer at the rate of 250 kg ha^{-1} and 200 kg ha^{-1} showed the highest plant height of potato (86.73 cm and 87.07 cm), respectively, while the shortest plant height (76.53 cm) was observed on plants without NPS fertilizer. When PS fertilizer amount decreased by half, the plant height decreased and statistically not significantly different with the control which conforms to the results in the application of S alone or S containing fertilizers (Choudhary, 2013) up to certain levels. The increase in plant height with the increased application of S and P might be due to its role in the growth and physiological functioning of plants (Haneklaus *et al*., 2007). Also, the increase in growth parameters under S application might be due to improved S availability, which in turn enhanced the plant metabolism and photosynthetic activity (Jat *et al*., 2013) and P enhanced the development of roots for nutrient uptake resulting into better growth (Solomon *et al*., 2019).

The maximum NPS fertilizer rate shows long maturity days may be due to luxury consumption of N and S elements (Gómez *et al*., 2018). Increasing NPS application rates in generally increased marketable, unmarketable and total tuber yields of the tested potato varieties (Melikamu and Minwyelet, 2018). Application of NPS fertilizer increased tuber yields of potato in agreement with the findings of different researchers who reported positive response of potato for tuber yields with increasing levels of NPS fertilizer rates at different agro-ecologies (Israel *et al*., 2012; Minwyelet, 2017; Shege *et al*., 2017; Melikamu and Minwyelet, 2018).

2.6.5. Effect of Zinc fertilizer on growth and yield of potato

According to the Food and Agriculture Organization (FAO), about 30% of the cultivable soils of the world contain low levels of plant available Zn (Hafeeze *et al*., 2013). Zinc is an important micro-nutrient needed for good growth and performance of potato (Raskshya and Arjun, 2019). Zinc exerts a great influence on basic plant life processes, such as: nitrogen metabolism and uptake of nitrogen, photosynthesis and chlorophyll synthesis (Tahmorespour *et al*., 2013). Foliar application of Zn significantly affected the potato height, stem number, canopy coverage and tuber yield (Raskshya and Arjun, 2019). The importance of Zn in improving the ratio of the indole-3-acetic acid (IAA) to abscisic acid (ABA) and cytokinin to ABA which promotes the formation and growth of stolons due to increased gibberellin content as result of reduced ABA content (Puzina, 2004). Foliar application of 0.2 % Zn individually produced maximum growth and yield of okra (Rahman *et al*., 2017). Foliar application of 1% zinc sulphate solution at 250L/ha increased potato yield by 200% (Aasen, 1987).

3. MATERIALS AND METHODS

3.1. Description of the Study Site

The study was conducted at Debre Berhan University, College of Agriculture and Natural Resource Sciences demonstration and research field in 2023. The study area is located at 130 Km from the capital Addis Ababa at an elevation of 2840 m.a.s.l (meter above sea level), with a latitude and longitude of $9^0 41'$ N $39^0 32'$E and 9.683^0N 39.533^0E respectively. The data obtained from the Ethiopian national meteorological agency indicates that the study area receives a mean annual rainfall of 927.10 mm and is characterized by a bimodal rainfall pattern with a maximum (293.02 mm) and minimum (4.72 mm) peaks in August and December respectively. The average monthly maximum and minimum temperatures range from 18.3 ^{0}C to 21.8 ^{0}C and from 2.4 to 8.9 ^{0}C, respectively. According to the FAO soil classification system, the most dominant soil in the area is vertisol and cambisol (FAO, 1984). Major crops grown in the study area are wheat, barely, pea, haricot bean, potato, carrot, apple and garlic.

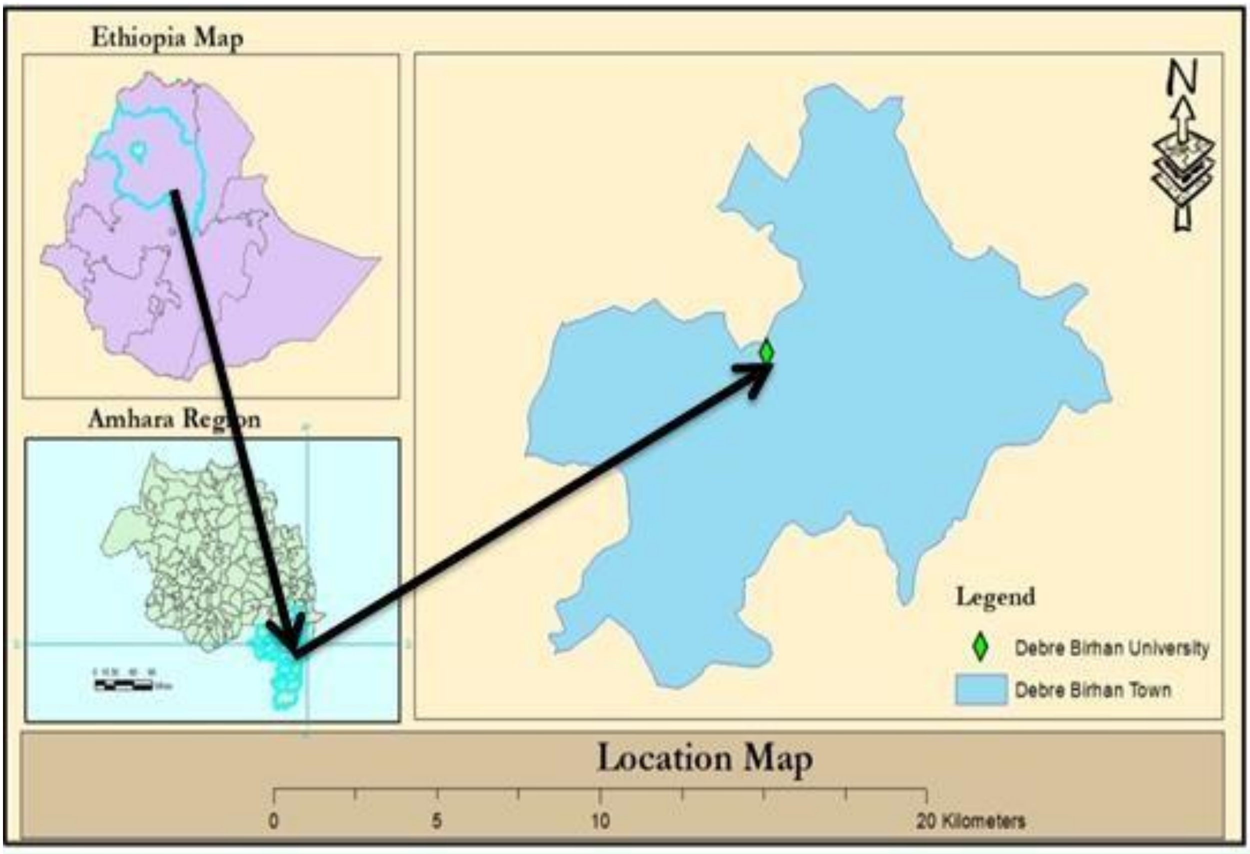

Figure 1.Map of the study area

3.2. Experimental material

The potato cultivar "Belete" was used as experimental material. It was obtained from Debre Berhan Agricultural Research Center. "Belete" was released by the Holetta Agricultural Research Center in 2009. Belete is adapted to areas situated between 1600 and 2800 meters above sea level and receiving an annual rainfall of 750 to 1000 mm. It is comparatively resistant to potato late blight disease (John, 2017). The number of days needed for "Belete" cultivar to attain maturity ranges between 90 and 120 days. The productivity in the research center and farmers' fields was 47.2 t/ha and 28-33.8 t/ha, respectively (Arega *et al*., 2018). The fertilizer sources used were Blended NPS, which constitutes 19% N, 38% P_2O_5, and 7% S, and 36% Zinc sulfate ($ZnSO_4$) was used as a source of Zinc.

3.3. Treatments and experimental design

The treatments consisted four levels of NPS blended fertilizer application rates (0, 90, 180 and 270 kg ha^{-1}) (MoA, 2009) and four levels of Zinc (0, 225, 450 and 675 ppm ($mg.l^{-1}$) (Al-Bayati & Ali, 2019). The experiment was laid out in a randomized complete block design (RCBD) with three replications in factorial arrangement of sixteen treatment combinations. In accordance with the specification of the design, a field layout was prepared and each treatment was assigned randomly to experimental plots within a block.

3.4. Experimental procedure and crop management

The experimental field was plowed to a depth of about 25-30 cm using a tractor, and the plots were leveled manually. Planting of tubers was done in June 2023 at Debre Berhan University's agricultural demonstration site. In total, there were 16 treatment combinations, with treatment applied to 48 plots covering a gross area of 11.25 m^2 (3 m in length and 3.75 m in width), each containing five rows. Each row accommodated 10 plants, resulting in a total population of 50 plants per plot, spaced at 0.75 m between rows and 0.30 m between plants (EIAR, 2007). The net plot size was 2.4 m x 2.25 m (5.4 m^2). The area of the experimental field was 55.5 m x 13.25 m. The distance between blocks and between plots was 1 m and 0.5 m, respectively. Well-sprouted medium-sized (39-75 g) seed tubers with a sprout length of 1.5 to 2.5 cm (Lung'aho *et al*., 2007) were planted. The two outer rows were designated as borders. NPS fertilizer was applied at the time of planting. The recommended rate of urea (210 kg/ha) was uniformly applied to all plots in two equal splits, with the first application applied after full emergence and the second at 50% flowering. Zinc sulfate ($ZnSO_4$) was used as the source of

Zinc. Spraying of Zinc sulfate was conducted at 45, 60, and 75 days after planting, and the application was done in the evening to reduce evaporation loss using a knapsack sprayer. Earthing-up was performed twice before flowering to initiate tuber bulking and once after blooming to prevent direct sun exposure to the tubers. Other management activities such as weeding, cultivation, disease, and insect pest control were carried out uniformly for each plot as described by EIAR (2007).

3.5. Soil sampling and analysis

Soil samples were taken randomly from the entire experimental field following a zigzag pattern from 0 to 30 cm depth before planting using an auger. The soil samples were combined into one composite sample. This composite soil sample was air-dried, crushed with a pestle and mortar to pass through a 2 mm sieve size for the analysis of physical and chemical properties. Total nitrogen (%), available phosphorus (mg/kg), cation exchange capacity (cmol(+)/kg), exchangeable potassium (Cmol/kg), available sulfur (mg/kg), available zinc (mg/kg), organic carbon (%), organic matter (%), soil pH (1:2.5), and soil texture were determined in the laboratory from the submitted sample. The soil pH was estimated from the filtered suspension of 1:2.5 soil-to-water ratio using a glass electrode attached to a digital EC and pH meter (Jones, 2003). The textural class was determined using the hydrometer method (Bouyoucos, 1962), and the organic carbon of the soil was determined following the wet digestion method as described by Walkley and Black (1934), while the percentage of organic matter of the soil was determined by multiplying the percent organic carbon value by 1.724. The particle size distribution of the soils was analyzed by the Bouyoucos hydrometer method (Day, 1965). The exchangeable bases and CEC of the soil were determined by the ammonium acetate method (Van Reeuwijk, 1993). The total nitrogen content was determined by the micro-Kjeldahl method (Bremner and Mulvaney, 1982), and available phosphorus and sulfur were determined using the Mehlich III multi-nutrient extraction procedure (Mehlich, 1984). Available zinc and potassium were determined using the AD-DTPA (diethylene triamine pentaacetic acid) method (Ryan *et al*., 2001).

3.6. Data collected

3.6.1. Phenological data

Days to 50% emergence: **-** It was recorded as the number of days from planting to 50% emergence of the plants in each net plot.

Days to 50% flowering (days):- Days to flowering in each plot were recorded by counting the number of days elapsed from the time of planting until 50% of the plants in the plot flowered.

Days to 75% maturity (days): The number of days from emergence to physiological maturity was recorded when 75% of the plants per plot were ready for harvest, as observed by the senescence of the haulms or plants with yellowish leaves.

3.6.2. Growth parameters

Plant height (cm): The height of ten randomly selected plants from the central rows was measured with the tape meter at the physiological maturity stage, from the ground surface to the tip of the main stem, and averaged to obtain the mean plant height.

Main stems number per hill (count): The stems that originated from the tuber were counted from ten plants randomly taken per hills at 50% flowering, and taking the average.

Average number of branches per plant: - The numbers of branches were recorded from ten randomly selected plants per plot at physiological maturity stage. Except for the main stem numbers of plants above the ground all other are considered as branch number.

3.6.3. Yield and yield components

Average tuber weight (g/tuber): - It was determined by dividing the total fresh tuber yield of randomly sampled five plants to the respective total tubers number.

Marketable tuber number per hill: The number of tubers harvested from five randomly selected plants per plot, which were considered marketable after sorting tubers weighing greater or equal to 25 g and free from disease and insect damage, was counted. The average number of marketable tubers was then recorded accordingly (Lung'aho *et al*., 2007).

Unmarketable tuber number per hill: The tubers sorted as diseased, insect-attacked, and small-sized (< 25 g), from five randomly selected plants per plot as indicated above, were recorded as the number of unmarketable tubers. The average number of unmarketable tubers was then counted and registered for each plot accordingly (Lung'aho *et al*., 2007).

Total tuber number hill^{-1}: The total tuber number per hill was obtained by counting and adding up the number of marketable and unmarketable tubers.

Marketable tuber yield (t ha^{-1}): The tubers that were sorted and counted from randomly selected plants as marketable tuber were weighted and converted to marketable tuber yield in tons per hectare from net plot.

Unmarketable tuber yield (t ha^{-1}): The average weight of tubers which were unhealthy, injured by insect pests, with defects and less than 25g weight category from net plots tubers were recorded and calculated to t ha^{-1}.

Total tuber yield (t ha^{-1}): The total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tuber and later extrapolated to per hectare.

Tuber size distribution by weight (%): It is the proportional weight of tuber size categories that were taken at harvest. All tubers from plants in the central rows of each plot were categorized into small (<39g), medium (39-75g), and large (>75g) based on Lung'aho *et al*., (2007). Subsequently, the count for each of these categories was determined, and the proportion of the weight of each tuber category was expressed as a percentage."

3.6.4 Tuber quality parameters

Tuber dry matter content (%): was measured from five fresh tubers in each plot. The randomly taken tubers were weighed at harvest, sliced and dried in oven at 75^{o}C until a constant weight was obtained and dry matter in percent was calculated according to Williams and Woodbury (1968) as follows.

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

Specific gravity of tubers: A 5 kg tuber of all shapes and size categories were randomly be taken from each plot and washed with water. The tubers were then be weighted first in air then in water. The specific gravity was then calculated using the following formula (Klein Kopf *et al*., 1987).

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

Total starch content (g/100g): - The percentage of starch was calculated from the specific gravity using the following equation (Talburt and Smith, 1959).

$$\textbf{Starch}(\%) = \mathbf{17.546} + \mathbf{199.07} \times (\textbf{specific gravity - }\mathbf{1.0988})$$

3.7. Partial budget analysis

The economic analysis was carried out using the methodology described in CIMMYT (1988), where prevailing market prices for inputs at planting and outputs at harvesting were considered. All costs and benefits were computed on a per-hectare basis in Eth-Birr. The concepts used in the partial budget analysis were the mean marketable tuber yield of each treatment. The economic gains of the different treatments were calculated to approximate the net returns and the cost of NPS, Zinc, and the income from total potato tubers used for further economic analysis. Additionally, market prices of NPS, Zinc fertilizer, marketable tubers, and labor costs were obtained from market assessments during the observational period.

Gross average marketable tuber yield (kg ha^{-1}) (AvY): AvY was an average yield of each treatment.

Adjusted yield (AjY): AjY was the average yield adjusted downward by a 10% to reflect the difference between experimental yields are often higher than the yields that farmers could expect using the same treatments; hence in economic calculations, yields of farmers are adjusted by 10% less than that of the research results (CIMMYT, 1988).

Adjustable marketable tuber yield = Average yield - (Average yield*0.1)

Gross field benefit (GFB): GFB was computed by multiplying field/farm gate price that farmers receive for the potato when they sale it as adjusted marketable tuber yield.

Gross field benefit (GFB) = Adjustable marketable tuber yield*field/farm gate price for potato.

Total variable cost (TVC): Total cost was the cost of fertilizers and application cost of fertilizers as differing dosages for the experiment. The costs of other inputs and production practices such as labor cost, land preparation, planting, earthing up, weeding, and harvesting were considered the same or are insignificant among treatments.

Net Income (NI) or Net Benefit (NB): - was calculated as the amount of money left when the total variable costs for inputs (TVC) are deducted from the total revenue (TR).

$$\mathbf{NB = TR - TVC}$$

Marginal rate return (MRR): was the measure of increasing in return by increasing input.

$$\mathbf{MRR} = \frac{\textbf{Change of Net Benefit } (\boldsymbol{\Delta NB})}{\textbf{Change of Total Variable Cost} (\boldsymbol{\Delta TVC})}$$

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

$$\mathbf{MRR\ \%} = \frac{\textbf{Change of Net Benefit } (\boldsymbol{\Delta NB})}{\textbf{Change of Total Variable Cost} (\boldsymbol{\Delta TVC})} * \mathbf{100}$$

Dominance analysis (identification and elimination of inferior treatments): is also used to eliminate those treatments which involve higher cost but do not generate higher benefits. Any treatment that has higher TVC but net benefits that are less than or equal to the preceding treatment (with lower TVC but higher net benefits) is dominated treatment (marked as **"D"**). Thus, the treatment which was non-dominated and having an MRR of greater or equal to 100% with the highest net benefit was taken to be economically profitable.

3.8. Correlation analysis

The correlation analysis was done for the growth, yield, yield components and quality parameters of potato as affected by the application of NPS and Zinc fertilizer and done according to Carey (1998).

3.9. Data analysis

Data was subjected to analysis of variance (ANOVA) using SAS version 9.31 (SAS Institute Inc., 2012). All significant pairs of treatment means were compared using Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) at a 5% level of significance. Correlation analysis was conducted for growth, yield, yield components and quality of potato.

4. RESULTS AND DISCUSSION

4.1. Soil physico-chemical properties of the experimental site before planting

The physico-chemical attributes of the soil sample taken before sowing suggested that sandy 20%, clay 46% and silt 34% and this could be categorized as clay soil based on USDA (1987) textural soil classification scheme (Table 1). The soil of the experimental field is slightly acidic (6.10) (Table 1). According to, (Bruce and Rayment, 1982) soil pH from (6.1 to 6.5) categorized as slightly acidic. The optimum pH range for potato requirement is between 5.2-6.5 (Fageria *et al*., 2011). Landon (1991) classified that topsoil having CEC greater than 40 cmol (+) kg^{-1} related as very high and 25-40 cmol (+) kg^{-1} as high, while 15-25, 5-15 and <5 cmol (+) kg^{-1} of CEC soil are classified as medium, low and very low respectively. According to this categorization, the soil of the experimental site had high CEC, which was 37.65 meq /100g, indicating its high capacity to retain cations. The soils with high CEC are suitable for potato production. The EC content of the experimental soil was 0.094ds/m. According to, Ethiosis Team Analysis (2014) and Muhr *et al*. (1963), classified soil EC availability of < 2 ds/m salt free, 2.4 ds/m very slightly saline, 4-8 ds/m slightly saline, 8-16 ds/m moderately saline and >16 ds/m Strongly saline.

The total organic carbon of the experimental field was 1.48 (Table 1) which is grouped under low. Total OC (%) greater than 10 as higher, 4-10 as medium and less than 4 as low (Booker, 1991). The organic matter (OM) content of the experimental soil was 2.55%. According to, rating of Tekalign (1991), OM ranging from 0.86 to 2.59 is low. The total nitrogen of the research site was 0.14% (Table 1). According to, Tekalign *et al*. (1991) classification, soil N availability of < 0.05% as very low, 0.05-0.12% as poor, 0.12-0.25% as medium and > 0.25% as high.

The available P content of the experimental soil was 8.4 ppm (Table1). According to Olsen and Chapman (1954), P classified soil P availability of <3 ppm very low, 4-7 ppm low, 8- 11ppm medium, 12-20 ppm high, >20 ppm very high. The analysis of available K was 1.18 ppm. According to, Booker (1991) classified soil k availability of <0.05% as very low, 0.05-0.12% as poor, 0.12-0.25% as moderate and > 0.25% as high. The available Zn content of the experimental soil was 1.45 ppm (Table1). According to, EthioSIS team analysis (2014), classified soil Zn availability of < 1 ppm very low, 1-1.5 ppm low, 1.5-10 ppm optimum, 10-20 ppm high, >20 ppm very high. The analysis of available S was 4.82 ppm (Table 1). According to, Alemu Lelago *et al*. (2016) classified soil S availability of < 10 ppm very low, 10-20 ppm low, 20 - 80 ppm medium, 80-100 ppm high, >100 ppm very high. From the values of soil analysis, the very low content of sulfur and total OC (%) as well as the medium contents of total nitrogen and available phosphorus indicate that application of these nutrients is important for optimum production and might be yield-limiting factor for potato production in the study area.

Table 1. Selected physico -chemical properties of the experimental soil before planting of potato.

Soil physicochemical properties	Values	Ratings	References
Texture			
Sand %	20		
Silt %	34		
Clay %	46		USDA (1987)
Textural Class	clay		
Available phosphorus (ppm)	8.4	medium	Olsen (1954)
CEC [Cmol (+) kg^{-1} soil]	37.65	high	Murphy (2007)
pH	6.10	Slightly acidic	Bruce and Rayment (1982)
Total nitrogen	0.14	medium	Tekalign Tadesse *et al.* (1991)
Organic Matter (OM %)	2.55	low	Tekalign (1991)
Organic carbon (%)	1.48	low	Booker (1991)
EC (ds/m)	0.094	salt free	Ethiosis Team Analysis (2014) And Muhr *et al*. (1963)
Available sulfur (ppm)	4.82	very low	Alemu Lelago *et al*. (2016)
Available K (ppm)	1.18	high	Booker (1991)
Available Zn (ppm)	1.45	low	EthioSIS team analysis (2014)

Where Cmol = Centi mole, pH= power of hydrogen, % OC = per cent of organic carbon, %TN = Per cent of total nitrogen, AV. P. Ppm = available phosphorus in parts per million, CEC = Cation exchange capacity, OM = organic matter content, AV.K = available potassium, AV. Zn = available Zinc in parts per million. EC = electrical conductivity in decisiemens.

4.2. Phenological parameters of potato

4.2.1. Days to emergence

The analysis of variance revealed that the main effect NPS, zinc fertilizers and their interaction did not significantly ($p > 0.05$) affected days to emergence. The uniform emergence of the potato plants from all plots regardless of the variations in the applied doses of the fertilizers might be attributed to the fact that the sprouting process in potatoes is mainly controlled by the potential of the stored food in the seed tubers to drive and sustain emergence. Similarly, Lynch and Tai (1989) and De La Morena *et al*. (1994) reported that the emergence of potato tuber was affected by storage conditions and physiological age of the seed tubers rather than being disciplined by the fertility status of the land.

Banerjee *et al*. (2016) stated that zinc application did not significantly influence the germination percent in potato. It might be due to the fact that food material already stored in the seed tubers gave initial boost to the emerging plants.

Table 2. The main effects of NPS and Zinc fertilizers on days to emergence at Debre Berhan during 2023 cropping season.

Fertilizer rates	Days to emergence
NPS (kg ha^{-1})	
0	19.33^{a}
90	19.75^{a}
180	19.83^{a}
270	19.92^{a}
DMRT (significance)	ns
Zinc (ppm)	
0	19.58^{a}
225	19.67^{a}
450	19.75^{a}
675	19.83^{a}
DMRT (significance)	ns
CV (%)	3.97

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.2.2. Days to 50% flowering

The number of days to 50% flowering was significantly ($p \leq 0.01$) influenced by NPS fertilizer. However, neither the main effect of Zn nor the interaction effect of NPS and Zn had a significant impact on this parameter (Appendix Table1). The longest days (61.67) required to reach days to 50% flowering was recorded from the application of 270 kg ha^{-1} NPS fertilizer which was statistically similar with the application of 180 kg ha^{-1} NPS. On the other hand, the shortest days (60.50) to 50% flowering was recorded from the control treatment (Table 3). The longest duration observed could be attributed to the increased rate of NPS fertilizer, resulting in excessive haulm development, which in turn leads to a prolonged period required to achieve 50% flowering.

In agreement with this, Jafer (2023) stated that the longest duration required to reach days to 50% flowering was recorded from the application of 150 kg/ha NPS while the shortest duration to 50% flowering was recorded from the control treatment. Gedefa *et al.* (2022) also suggested that the application of the highest rate of NPS fertilizer at a rate of 200 kg ha^{-1} resulted in the longest duration to flowering. However, the shortest duration to 50% flowering was obtained from the control treatment. In addition, Lakew and Fanuel (2021) demonstrated that the longest period required to reach days to 50% flowering was recorded from the application of 250 kg/ha NPS while the shortest duration to 50% flowering was recorded from the control treatment. Moreover, Getacher (2021) confirmed that the maximum period required to 50% flowering was recorded from the application of 180 kg ha^{-1} NPS, whereas the shortest duration to 50 % flowering was recorded from the control treatment. But in contrast to this, Minwyelet *et al.* (2017) and Getachew *et al.* (2016) observed that there were no significant differences in days to flowering in potato due to the application of different level of NPS fertilizer treatment.

4.2.3. Days to physiological maturity

The number of days to 75% physiological maturity was significantly ($p \leq 0.05$) influenced by the main effect of NPS fertilizer. However, neither the main effect of Zn nor the interaction effect of NPS and Zn had a significant impact on this parameter (Appendix Table 1). The longest duration to maturity (121.67 days) was recorded from the application of 270 kg ha^{-1} but statistically having a similar days with the application of 180 and 90 kg ha^{-1} NPS. Whereas, the shortest duration to 75 % maturity (120.33 days) was recorded from the control treatment (Table 3).The extended time required for maturity resulting from increased NPS fertilizer application could be attributed to the abundant consumption of nitrogen (N) and sulfur (S) elements. These elements activate enzyme functions and promote chlorophyll production, which, in turn, enhances the interception of solar energy and encourages plant growth and development.

Similarly, Getacher (2021) found that the maximum period required to 75% maturity was recorded from the application of 180 kg ha^{-1} NPS, whereas the shortest duration to 75 % maturity was recorded from the control treatment. Mekides *et al*. (2020) and Gómez *et al*. (2018) also reported that applying a maximum rate of NPS fertilizer to potatoes prolonged maturity days. In addition, Melkamu *et al.* (2016) stated that increasing the rate of NPS fertilizer application delayed days to physiological maturity. Furthermore, Melkamu and Minwyelet (2018) and Isreal *et al*. (2012) also reported that application of N, P, and S fertilizer showed significant effect on prolonging time of maturity.

Table 3. Phenological parameters of potato as affected by NPS fertilizer application rates at Debre Berhan during 2023 cropping season.

NPS (kg ha^{-1})	days to 50% flowering	days to maturity
0	60.50^{b}	120.33^{b}
90	60.83^{b}	120.92^{ab}
180	61.58^{a}	121.58^{a}
270	61.67^{a}	121.67^{a}
DMRT(significance)	**	*
CV	1.46	0.92

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.3. Growth parameters of potato

4.3.1. Plant height

The analysis of variance revealed that the main effects of NPS fertilizer, zinc and their interaction had a significant ($p \leq 0.001$) effect on plant height (Appendix Table 1). The tallest plant height (81.83 cm) was recorded from plants that grow with the combined application of 270 kg ha^{-1} NPS and 450 ppm zinc fertilizer which was statistically similar with the combined application of 180 kg ha^{-1} NPS with 450 and 675 ppm zinc and 270 kg ha^{-1} NPS and 675 ppm zinc. On the other hand, the shortest plant height (61.61 cm) was recorded from the control treatment. The increase in plant height due to the application of 270 kg ha^{-1} NPS and 450 ppm zinc fertilizer was by 20.22, 0.45 and 3.93 cm as compared to the control treatment, 180 kg ha^{-1} NPS with 450 ppm Zn and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 4). The height increase in potato plants resulting from the application of increased NPS and zinc fertilizers could be attributed to the elevated levels of macro and micro nutrients, including nitrogen, phosphorous, sulfur, and zinc. These nutrients enhance cell division and vegetative growth, leading to the formation of chlorophyll and chloroplasts. Consequently, this promotes higher photosynthetic activity, vigorous vegetative growth, and taller plants.

In agreement with this, Temesgen and Getachew (2023) and Lakew and Fanuel (2021) reported that the highest plant height was recorded from 250 kg ha^{-1} NPS fertilizer whereas the shortest plant height was observed from the control treatment. Gedefa *et al*. (2022) also stated that the longest plant height was recorded from the highest rate of NPS (200 kg ha^{-1}) fertilizer. On the other hand the shortest plant height was obtained from the control treatment. In addition, Abraham (2019) described that the tallest plant height was resulted from 300 kg ha^{-1} NPS fertilizer while the shortest plant height was recorded from the control treatment.

Manea *et al*. (2019) found that spraying zinc sulphate for potato plants with the concentration of 400 ppm caused a significant increase in plant height. Ahmed *et al*. (2011) also reported that the highest plant length was recorded with the highest concentration of zinc (300 ppm) compared with the control treatment. In addition, Kumar *et al*. (2008) observed that foliar application of Zn helped to improve plant height of potato.

Table 4. The interaction effects of NPS and Zinc fertilizer on growth parameters of potato at Debre Berhan during 2023 cropping season.

NPS (kg ha^{-1})	Zinc (ppm)	Plant height (cm)	Main stem number (plant^{-1})	Average number of branches (plant^{-1})
0	0	61.61^{g}	2.17^{g}	7.17^{g}
	225	63.41^{fg}	3.07^{f}	7.93^{fg}
	450	64.84^{ef}	3.27^{ef}	8.80^{ef}
	675	66.82^{de}	3.83^{de}	8.90^{d-f}
90	0	67.47^{de}	3.83^{de}	9.83^{de}
	225	69.40^{cd}	4.00^{de}	10.03^{c-e}
	450	71.05^{c}	4.27^{d}	10.30^{c-e}
	675	72.02^{c}	4.43^{cd}	10.53^{cd}
180	0	77.90^{b}	5.03^{bc}	11.53^{c}
	225	77.58^{b}	5.23^{b}	13.87^{b}
	450	81.38^{a}	5.63^{ab}	15.57^{a}
	675	79.04^{ab}	5.53^{ab}	14.63^{ab}
270	0	77.97^{b}	5.17^{bc}	10.43^{c-e}
	225	78.25^{b}	5.53^{ab}	14.73^{ab}
	450	81.83^{a}	6.03^{a}	16.00^{a}
	675	79.23^{ab}	5.53^{ab}	14.93^{ab}
DMRT(significance)		***	***	***
CV (%)		2.19	9.09	7.61

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.3.2. Main stem number per plant

The analysis of variance revealed that the main effect of blended NPS fertilizer and their interaction showed a significant ($p \leq 0.001$) difference on main stem number while significantly ($p \leq 0.01$) influenced by the main effect of zinc (Appendix Table 1). The highest main stem number (6.03) was obtained by the application of 270 kg/ha NPS and 450 ppm zinc fertilizer which was statistically similar with the application of 180 kg ha^{-1} NPS with 450 and

675 ppm zinc and 270 kg/ha NPS with 225 and 675 ppm zinc fertilizer. On the other hand, the lowest number of main stems (2.17) was obtained from the control treatment. The increase in number of main stems due to the application of 270 kg ha^{-1} NPS and 450 ppm zinc fertilizer was by 177.88%, 7.10% and 19.88% as compared to the control treatment, 180 kg ha^{-1} NPS with 450 ppm Zn and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 4). The main stem number increase in potato plants resulting from the application of increased NPS and zinc fertilizers could be might be due to the nutritional effects of nutrients that are found in NPS fertilizer and zinc which enhanced the activation of dormant sprouts to be developed into stems.

In line with this, Jafer (2023) reported that potato grown with the highest rate of 150 kg ha^{-1} NPS fertilizer recorded the highest main stem number whereas the lowest main stem number was obtained from the control treatment. Gedefa *et al*. (2022) also stated that the highest stem number per hill was recorded from the application of 200 kg ha^{-1} NPS fertilizer. On the other hand the lowest stem number per hill was recorded from the control treatment. In addition, Melkamu and Minwyelet (2018) and Solomon *et al.* (2019) indicated that the application of higher rates of NPS fertilizer significantly increased potato stem number. Furthermore, Minwyelet *et al*. (2017) indicated that increasing the application of NPS fertilizer rates from 0 to 272 kg ha^{-1} NPS fertilizer increased the main stem number of potato from 5.47 to 9.8 $hill^{-1}$.

Ahmed *et al*. (2011) found that spraying zinc sulphate for potato plants with the concentration 300 ppm caused a significant increase in number of stems per plant. Nizamudin *et al*. (2003), Alam *et al*. (2007) and Hassanpanah *et al*. (2009) also stated that the lowest stem number of potato was obtained from the control treatment.

4.3.3. Number of branches per plant

The main effects of blended NPS fertilizer, Zinc and their interaction showed a significantly ($p \leq 0.001$) difference on the number of branches (Appendix Table 1). The highest number of branches (16.00) was obtained by the combined application of 270 kg/ha NPS and 450 ppm zinc fertilizer which was statistically similar with the application of 180 kg ha^{-1} NPS with 450 and 675 ppm zinc and 270 kg ha^{-1} NPS with 225 and 675 ppm zinc while the lowest number of branches (7.17) was obtained from the control treatment. The maximum number of branches obtained by the combined application of 270 kg ha^{-1} NPS and 450 ppm zinc have shown a 123.15, 2.76 and 38.77% increment in branch number as compared to the control treatment, 180 kg ha^{-1} NPS with 450 ppm Zn and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 4). The increased in the number of branches as NPS and Zinc fertilizer rates increased might be due to the chief nutrient present in NPS and Zinc which enhance the growth of vegetative parts, improvement of soil water holding capacity and enhanced catalytic or stimulatory effect on most of the physiological and metabolic processes of plant.

Similarly, Yitbarek and Geletaw (2019) reported that increased the primary branches as the NPS rate increased and a higher rate of NPS promote primary branches, during vegetative development and also help to maintain functional branches during the vegetative growth of tomato. Ahmed (2024) also stated that the highest number of branches was observed in 0.75% Zinc in chili. Whereas, the lowest number of branches was observed in the control treatment.

4.4. Yield and yield components of potato

4.4.1. Average tuber weight

The analysis of variance indicated that average tuber weight was significantly ($p \leq 0.001$) affected by the main effect of NPS fertilizer and their interaction while significantly ($p \leq 0.05$) influenced by the main effect of zinc (Appendix Table 1).The highest average tuber weight (88.60g tuber^{-1}) was recorded by the application of 180 kg ha^{-1} NPS and 450 ppm zinc fertilizer which was statistically similar with the application of 180 kg ha^{-1} NPS and 675 ppm zinc. On the other hand, the lowest average tuber weight (62.55g tuber^{-1}) was recorded from the control treatment. The increase in average tuber weight due to the application of 180 kg ha^{-1} of NPS and 450 ppm zinc was by 41.65 and 8.14% as compared to the control treatment and 180 kg ha^{-1} NPS fertilize application, respectively (Table 5). The increase in average tuber weight may be attributed to the efficient utilization of nutrients by potato plants. Additionally, the applied fertilizer could have enhanced nutrient availability, leading to greater leaf area, improved vegetative growth, increased water use efficiency, and enhanced physiological processes. These factors collectively contributed to the larger size and weight of the tubers.

Similarly, Temesgen and Getachew (2023) described that maximum average tuber weight was obtained from the application of 250 kg/ha NPS whereas the lowest average tuber weight was obtained from the control treatment. Lakew and Fanuel (2021) also reported that the highest average tuber weight was recorded from the application of 200 kg ha^{-1} NPS fertilizer. On the other hand, the lowest average tuber weight was recorded from the control treatment. In addition, Mekides *et al*. (2020) confirmed that the highest average tuber weight was recorded from 55.5: 89.7:16.52 kg ha^{-1} NPS fertilizer while the lowest average tuber weight was recorded from the control treatment.

Rakshya and Arjun (2019) found that maximum tuber weight was obtained from 180 ppm Zn-EDTA with two spray while the lowest tuber weight was obtained from the control treatment. Rahman *et al*. (2018) also stated that the highest weight of tubers per hill (0.63 and 0.61kg hill^{-1} for 2013-14 and 2014-15, respectively) was found in 560 ppm Zn while the lowest weight of tubers per hill (0.50 and 0.45 kg hill^{-1} for 2013-14 and 2014-15, respectively) was recorded from the control treatment. In addition, Mousavi *et al*. (2007) suggested that the weight of tuber was increased with foliar application of Zn at 800 ppm.

4.4.2. Marketable tuber yield

Marketable tuber yield was significantly ($p \leq 0.001$) affected by the main effect of NPS, zinc fertilizer and their interaction (Appendix Table 1). The highest marketable tuber yield (42.45 t ha^{-1}) was recorded by the combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizers which was statistically similar with 180 kg ha^{-1} of NPS and 675 ppm zinc and 270 kg ha^{-1} of NPS and 450 ppm zinc. However, the lowest marketable tuber yield (16.22 t ha^{-1}) was recorded from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased the marketable tuber yield by 161.71 and 26.91% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 5). The increase in marketable tuber yield resulting from the combined application of NPS and zinc fertilizer suggests that mineral nutrients play a role in producing larger and healthier tubers. This effect is attributed to the delay in tuber growth, which leads to greater allocation of dry matter to the above-ground portion and enhanced translocation of assimilates from leaves to tubers, ultimately contributing to the increased marketable tuber yield.

In line with this, Gedefa *et al.* (2022) described that increasing the rate of blended NPS fertilizer from 0 to 200 kg ha^{-1} increased marketable tuber yield significantly. Lakew and Fanuel (2021) also reported that the application of NPS fertilizer at a rate of 200 kg ha^{-1} produced the highest marketable tuber yield. However, the lowest marketable tuber yield was obtained from the control treatment. In addition, Mekides *et al*. (2020) suggested that the highest marketable tuber yield was obtained from potato which was supplied with 55.5: 89.7:16.52 kg ha^{-1} of NPS fertilizer rate while the lowest marketable tuber yield was obtained from the control treatment. Moreover, Abraham (2019) described that the application of NPS fertilizer at a rate of 300 kg ha^{-1} produced the highest marketable tuber yield. On the other hand, the lowest marketable tuber yield was obtained from the control treatment.

Rahman *et al*. (2018) described that the highest tuber yield of potato (37.2 and 36.7 t ha^{-1} for 2013-14 and 2014-15, respectively) was found in 560 ppm Zn while the lowest tuber yield (29.3 and 27.9 t ha^{-1} for 2013-14 and 2014-15, respectively) was recorded from the control treatment.

Table 5. Effect of blended NPS and zinc fertilizer rates on yield parameters of potato at Debre Berhan during 2023 cropping season.

Fertilizer rates				
NPS (kg ha^{-1})	Zinc (ppm)	Average tuber weight	Marketable tuber yield (t ha^{-1})	Total tuber yield (t ha^{-1})
0	0	62.55[h]	16.22[i]	21.91[i]
	225	66.73[gh]	21.89[h]	27.56[h]
	450	70.44[ef]	27.33[fg]	33.03[fg]
	675	71.94[e]	30.73[ef]	36.15[e-g]
90	0	71.12[ef]	25.41[gh]	31.33[gh]
	225	74.94[de]	27.89[fg]	33.43[fg]
	450	77.48[cd]	31.85[ef]	37.44[d-f]
	675	79.6[cd]	33.33[de]	38.23[d-f]
180	0	81.93[c]	33.45[de]	37.51[d-f]
	225	82.8[bc]	37.23[b-d]	41.75[a-d]
	450	88.60[a]	42.45[a]	46.06[a]
	675	87.52[ab]	40.41[ab]	44.89[ab]
270	0	82.84[bc]	33.01[de]	37.46[d-f]
	225	80.48[c]	34.13[c-e]	40.07[b-e]
	450	80.81[c]	38.93[a-c]	44.35[a-c]
	675	81.37[c]	33.91[c-e]	39.80[c-e]
DMRT(significance)		***	***	***
CV (%)		3.69	8.88	7.43

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.4.3. Unmarketable tuber yield

Unmarketable tuber yield was significantly ($p \leq 0.01$) affected by the main effect of NPS fertilizer. However, neither the main effect of Zn nor the interaction effect of NPS and Zn had a significant impact on this parameter (Appendix Table 1).The maximum unmarketable tuber yield (5.62 t ha^{-1}) was recorded from the control treatment while the minimum unmarketable tuber yields (4.17 t ha^{-1}) was recorded by 180 kg ha^{-1} of NPS (Table 7). The increase in unmarketable tuber yield, resulting from the lack of NPS and Zn fertilizers, could be linked to essential nutrient deficiencies in the soil. These deficiencies lead to the production of undersized and decayed tubers, ultimately reducing the tuber yield.

Gedefa *et al*. (2022) and Lakew and Fanuel (2021) confirmed that the maximum unmarketable tuber yield was recorded from the control treatment. On the other hand, the minimum unmarketable tuber yield was obtained from 200 kg ha^{-1} NPS fertilizer. Getacher (2021) also reported that the lowest unmarketable tuber yield was recorded by the application of 180 kg ha^{-1} NPS fertilizer whereas the highest unmarketable tuber yield was obtained from the control treatment.

4.4.4. Total tuber yield

The analysis of variance indicated that the main effect of NPS, zinc fertilizers and their interaction had a significant ($p \leq 0.001$) effect on total tuber yield (Appendix Table 1).The highest total tuber yield (46.06 t ha^{-1}) was obtained from plots that received 180 kg ha^{-1} of NPS and 450 ppm zinc which was statistically similar with 180 kg ha^{-1} of NPS with 225 and 675 ppm zinc and 270 kg ha^{-1} of NPS and 450 ppm zinc. On the other hand, the lowest total tuber yield (21.91 t ha^{-1}) was obtained from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased the total tuber yield by 110.22 and 22.79% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 5). The increase in total tuber yield can be linked to enhanced nutrient availability and increased chlorophyll content. As a result, this led to a higher photosynthetic rate, which facilitated greater production and translocation of photosynthates to the potato tubers.

This result was in agreement with the findings of Lakew and Fanuel (2021) who demonstrated that the application of NPS fertilizer at a rate of 200 kg ha^{-1} produced the highest total tuber yield. However, the lowest total tuber yield was obtained from the control treatment. Mekides *et al*. (2020) also reported that the highest total tuber yield was obtained by the rate of 55.5:

89.7:16.52 kg ha^{-1} of NPS fertilizer while the lowest total tuber yield was obtained from the control treatment. In addition, Minwyelet *et al*. (2017) indicated that the application of NPS fertilizer at a rate of 272 kg ha^{-1} produced the highest total tuber yield whereas the lowest total tuber yield was obtained from the control treatment.

Manea *et al*. (2019) found that spraying zinc sulphate for potato plants with the concentration of 400 ppm caused a significant increase in total yield of tubers as compared with the control treatment. Sati *et al*. (2017) also noted that zinc application on potato crop improved the size of potato tuber, which directly leads to yield increase. In addition, Ahmed *et al*. (2011) found that the highest total tuber yield of potato was recorded with the highest application of zinc concentration at a rate of 300 ppm.

4.4.5. Marketable tuber number per plant

Marketable tuber number per plant was significantly ($p \leq 0.001$) affected by the main effect of NPS, zinc fertilizers and their interaction (Appendix Table 1). The highest marketable tuber number per plant (20.13) was recorded by the combined application of 180 kg ha^{-1} NPS and 450 ppm zinc fertilizers which was statistically similar with the application of 180 kg ha^{-1} NPS and 675 ppm zinc and 270 kg ha^{-1} NPS with 450 and 675 ppm zinc. On the other hand, the lowest marketable tuber number per plant (5.61) was recorded from the control treatment. The increase in Marketable tuber number per plant due to the application of 180 kg ha^{-1} of NPS and 450 ppm zinc was by 258.82 and 33.84% as compared to the control treatment and 180 kg ha^{-1} of NPS fertilizer application, respectively (Table 6). The increased number of marketable tubers resulting from the combined application of 180 kg ha^{-1} NPS and 450 ppm zinc fertilizers may be attributed to the utilization of nitrogen, sulfur, and phosphorus. This application led to a reduction in the number of small-sized tubers and an increase in the weight of individual tubers.

Similarly, Gedefa *et al.* (2022) and Lakew and Fanuel (2021) demonstrated that the highest marketable tuber number per hill was recorded from 200 kg ha^{-1} of NPS fertilizer whereas the lowest marketable tuber number per hill was recorded from the control treatment. Solomon *et al.* (2019) also stated that increasing NPS rate from 0-0-0 to 110- 19.74-50.8 kg/ha of N-S-P_2O_5 increased the number of marketable tubers by 127%.

Jenkins and Ali (2000) noted that the number of tubers varied considerably as a result of Zn fertilization, and doubled when Zn level was increased to higher levels.

Table 6. Effect of blended NPS and zinc fertilizer rates on marketable and total tuber number of potato at Debre Berhan during 2023 cropping season.

Fertilizer rates NPS (kg ha^{-1})	Zinc (ppm)	Marketable tuber number (plant^{-1})	Total tuber number (plant^{-1})
0	0	5.61^{g}	10.64^{g}
	225	5.97^{g}	10.90^{g}
	450	8.50^{f}	13.83^{f}
	675	10.00^{ef}	15.11^{ef}
90	0	9.82^{ef}	14.56^{ef}
	225	10.08^{ef}	15.20^{ef}
	450	11.00^{ed}	15.95^{de}
	675	12.51^{d}	17.67^{d}
180	0	15.04^{c}	19.65^{c}
	225	16.81^{bc}	21.31^{bc}
	450	20.13^{a}	23.54^{a}
	675	18.13^{ab}	22.35^{ab}
270	0	15.00^{c}	19.7^{c}
	225	16.77^{bc}	21.34^{bc}
	450	19.34^{a}	23.09^{ab}
	675	18.10^{ab}	22.42^{ab}
DMRT(significance)		***	***
CV (%)		9.08	6.34

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.4.6. Unmarketable tuber number per plant

Unmarketable tuber number per plant was significantly ($p \leq 0.01$) affected by the main effect of NPS fertilizer. However, neither the main effect of Zn nor the interaction effect of NPS and Zn had a significant impact on this parameter (Appendix Table 1). The highest unmarketable tuber number per plant (5.10) was recorded from the control treatment while the lowest unmarketable tuber number per plant (4.19) was recorded by 180 kg ha^{-1} NPS fertilizer (Table

7). The inadequate nutrient levels in the soil fail to meet the requirements of potatoes for vegetative growth, physiological processes, cell division, and stolon development.

In line with this, Gedefa *et al.* (2022) described that the maximum unmarketable tuber number per hill was recorded from the control treatment whereas the lowest unmarketable tuber number per hill was recorded from 200 kg ha^{-1} NPS fertilizer. Similarly, Lakew and Fanuel (2021) reported that the maximum unmarketable tuber number was recorded from the control treatment. However, the minimum unmarketable tuber number was recorded from 250 kg ha^{-1} NPS fertilizer. In addition, Getacher (2021) indicated that the lowest unmarketable tuber number was recorded from 180 kg ha^{-1} NPS fertilizer while the highest unmarketable tuber number was obtained from the control treatment.

Table 7. Effect of blended NPS fertilizer rates on unmarketable tuber number and unmarketable tuber yield of potato at Debre Berhan during 2023 cropping season.

NPS (kg ha^{-1})	Unmarketable tuber number ($plant^{-1}$)	Unmarketable tuber yield (t ha^{-1})
0	5.10^{a}	5.62^{a}
90	4.99^{a}	5.49^{a}
180	4.19^{b}	4.17^{b}
270	4.34^{b}	5.42^{a}
DMRT(significance)	**	**
CV	15.88	17.7

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.4.7. Total tuber number per plant

The analysis of variance revealed that the main effect of NPS, zinc fertilizers and their interaction had a significant ($p \leq 0.001$) effect on total tuber number per plant (Appendix Table 1). The highest total tuber number per plant (23.54) was recorded by the combined application of 180 kg ha^{-1} NPS and 450 ppm zinc which was statistically similar with the application of 180 kg ha^{-1} NPS and 675 ppm zinc and 270 kg ha^{-1} NPS with 450 and 675 ppm zinc while the lowest total tuber number per plant (10.64) was recorded from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased the total tuber number per plant by 121.24 and 19.8% as compared to the control treatment and 180kg ha^{-1} NPS fertilizer application, respectively (Table 6). The increase in the total number of tubers per hill resulting from the application of NPS and zinc rates may be attributed to several factors. Nitrogen (N) can stimulate vegetative growth, leading to increased photo-assimilate production. Additionally, phosphorus (P) enhances root development, facilitating nutrient uptake. Sulfur (S) plays a pivotal role in regulating physiological and metabolic processes in plants. Furthermore, zinc sulfate affects the hormonal status of potato plants.

Temesgen and Getachew (2023) indicated that the highest total tuber number per hill was obtained from 250 kg ha^{-1} NPS whereas the smallest total tuber number per hill was recorded from the control treatment. Gedefa *et al*. (2022) and Lakew and Fanuel (2021) also reported that the highest total tuber number per hill was recorded from 200 kg ha^{-1} NPS fertilizer. However, the smallest total tuber number per hill was recorded from the control treatment.

4.4.8. Tuber size distribution

4.4.8.1. Small sized Tubers

The proportion of small sized tubers of potato was significantly ($p \leq 0.001$) influenced by the main effects NPS, Zn and their interaction (Appendix table 1). The highest proportion of small sized tuber (40.84%) was obtained from the control treatment while the smallest proportion of small sized tuber (4.06 %) was produced from the combined application of 180 kg of NPS ha^{-1} and 450 ppm of Zinc (Table 8). The increased occurrence of small sized tubers in untreated plots and those receiving minimal nutrient application could be attributed to the low nutrient dosages, which hindered the bulking process of individual tubers.

Similarly, Jafer (2023) confirmed that the highest small sized tuber was observed from the control treatment while the smallest small sized tuber was obtained from 150 kg ha^{-1} NPS fertilizer. Gedefa *et al*. (2022) also stated that the highest small tuber size was obtained from the control treatment whereas the smallest small tuber size was recorded from the application of 200 kg ha^{-1} NPS fertilizer. In addition, Lakew and Fanuel (2021) and Asfaw *et al*. (2021) described that the lowest numbers of small-sized tuber was obtained from the application of 250 kg ha^{-1} of NPS fertilizer whereas the highest small-sized tuber number was recorded from the control treatment.

4.4.8.2. Medium sized tubers

The proportion of medium sized tubers of potato was significantly ($p \leq 0.001$) influenced by the main effects NPS, Zn and their interaction (Appendix table 1). The highest proportion of medium sized tuber (45.00%) was obtained from the combined application of 180 kg of NPS ha^{-1} and 450 ppm of Zinc. However, the smallest proportion of medium sized tuber (31.73 %) was obtained from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased medium sized tubers by 41.82 and 10.13% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 8). This could be due to the abundant supply of nutrients to the potato crop that contributes to vigorous growth, increased canopy size, and expanded leaf area. These factors enhance photosynthesis, ultimately leading to the production of medium tubers.

In line with this, Jafer (2023) explained that the greatest proportion of medium sized tuber was obtained from the application of 150 kg ha^{-1} NPS. On the other hand, the smallest proportion of medium sized tuber was recorded from the control treatment. Gedefa *et al*. (2022) also stated that the highest proportion of medium sized tuber was recorded by the application of 200 kg ha^{-1} NPS fertilizer whereas the lowest proportion of medium sized tuber was obtained from the control treatment. In addition, Asfaw *et al*. (2021) described that the greatest proportion of medium sized tuber was obtained from the application of 250 kg ha^{-1} NPS fertilizer while the smallest proportion of medium sized tuber was recorded from the control treatment. Sharma *et al*. (1988) reported that application of zinc increased the number of medium sized tubers.

4.4.8.3. Large sized tuber

The proportion of large sized tubers of potato was significantly ($p \leq 0.001$) influenced by the main effects NPS, Zn and their interaction (Appendix table 1). The highest proportion of large sized tuber (50.94%) was obtained from the combined application of 180 kg ha^{-1} of NPS and 450 ppm of Zinc which was statistically similar with the application of 180 kg ha^{-1} of NPS and 675 ppm of Zinc. On the other, hand the smallest large sized tuber (27.43%) was obtained from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased large sized tubers by 85.71 and 11.47% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 8). This could be due to the abundant supply of nutrients to the potato crop that contributes to vigorous growth, increased canopy size, and expanded leaf area. These factors enhance photosynthesis, ultimately leading to the production of larger tubers.

In agreement with this, Jafer (2023); Gedefa *et al*. (2022) and Lakew and Fanuel (2021) reported that the highest proportion of large sized tuber was obtained from 200 kg ha^{-1} NPS fertilizer whereas the lowest proportion of large sized tuber from the control treatment.

Banerjee *et al.* (2016) observed that with Zn application there was significant improvement in tuber number for bigger sized potato which results in higher tuber yield of large sized potato. Sharma *et al*. (1988) also noted that application of zinc increased the number of large sized tubers.

Table 8. Effect of blended NPS and zinc fertilizer rates on tubers size distribution based on weight of potato tuber at Debre Berhan during 2023 cropping season.

Fertilizer rates		Tuber size distribution		
NPS (kg ha^{-1})	Zinc (ppm)	Small size tubers (%)	Medium Size tubers (%)	Large size tubers (%)
0	0	40.84[a]	31.73[j]	27.43[k]
	225	28.71[b]	38.63[d-g]	32.66[j]
	450	22.50[cd]	38.26[e-h]	39.24[gh]
	675	23.43[cd]	36.92[g-i]	39.71[g]
90	0	27.79[b]	35.73[i]	36.48[i]
	225	24.37[c]	37.22[f-i]	38.41[h]
	450	21.31[d]	37.33[f-i]	41.36[f]
	675	22.18[cd]	36.39[hi]	41.44[f]
180	0	13.44[f]	40.86[bc]	45.70[c]
	225	9.88[g]	42.33[b]	47.79[b]
	450	4.06[h]	45.00[a]	50.94[a]
	675	7.88[g]	42.24[b]	49.89[a]
270	0	17.97[e]	39.49[c-e]	42.54[ef]
	225	18.50[e]	38.61[d-g]	42.89[e]
	450	16.10[e]	40.42[b-d]	43.48[de]
	675	16.61[e]	39.09[c-f]	44.31[d]
DMRT(significance)		***	***	***
CV (%)		7.73	2.91	1.76

Mean values sharing the same letter in each column are not a significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.5. Quality parameters of potato

4.5.1. Tuber dry matter content

The analysis of variance indicated that tuber dry matter content was significantly ($p \leq 0.001$) affected by the main effect of NPS fertilizer, zinc and their interaction (Appendix Table1). The highest tuber dry matter content (28.04%) was recorded by the application of 180 kg ha^{-1} NPS and 450 ppm zinc while the lowest tuber dry matter content (18.68%) was recorded from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased tuber dry matter content by 50.11 and 15.25% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 9). The highest tuber dry matter content due to the combined application of 180 kg ha^{-1} NPS and 450 ppm zinc could be attributed to the more partitioning of photosysnthates towards tuber from foliage that resulted in a higher tuber dry matter production.

In agreement with this, Jafer (2023) and Feysel (2020) observed that the highest tuber dry matter content was obtained due to the application of 150 kg ha^{-1} NPS fertilizer whereas the lowest dry matter content was obtained from the control treatment. Debebe (2023); Gedefa *et al*. (2022) and Mekuannet *et al*. (2022) also reported that the highest dry matter content was produced due to the application of 200 kg ha^{-1} NPS fertilizer whereas the smallest dry matter content was obtained from the control treatment.

Rahman *et al*. (2018) found that the highest dry matter content (20.7 and 21.1% for 2013-14 and 2014-15, respectively) was noted by the application of 560 ppm Zn while the minimum dry matter content (18.7 and 18.8% for 2013-14 and 2014- 15,respectively) was noted from the control treatment. Ahmed *et al*. (2011) also observed that maximum dry matter content of potato tubers was due to the foliar application of zinc at a rate of 300 ppm. However, the lowest dry matter content of potato tubers was recorded from the control treatment.

4.5.2. Specific gravity

The specific gravity of tubers was significantly ($p \leq 0.001$) affected by NPS, zinc fertilizer and their interaction (Appendix Table 1). The highest specific gravity (1.096g/cm^3) was obtained from the application of 180 kg ha^{-1} NPS and 450 ppm zinc which was statistically similar with the application of 180 kg ha^{-1} NPS with 225 and 675 ppm zinc and 270 kg ha^{-1} NPS and 675 ppm zinc. On the other hand, the lowest specific gravity (1.058 g/cm^3) was recorded from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased specific gravity by 3.59 and 0.74% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 9). This could probably be due to its association with the increased stored assimilates in potato tubers.

Similarly, Jafer (2023) and Feysel (2020) confirmed that the highest specific gravity was registered from 150 kg ha^{-1} NPS fertilizer. However, the lowest specific gravity was obtained from the control treatment. Debebe (2023); Gedefa *et al*. (2022) and Mekuannet *et al*. (2022) also described that the highest specific gravity was produced due to the application of 200 kg ha^{-1} NPS fertilizer. On the other hand, the smallest specific gravity was obtained from the control treatment.

Ahmed *et al*. (2011) indicated that the highest specific gravity of potato tubers was obtained from the highest foliar application of zinc at a rate of 300 ppm. However, the lowest specific gravity was recorded from the control treatment.

4.5.3. Tuber starch content

The analysis of variance indicated that the main effects NPS fertilizer, zinc and their interaction had a significant ($p \leq 0.001$) effect on tuber starch content (Appendix Table 1). The highest tuber starch content (16.92%) was resulted from the application of 180 kg ha^{-1} NPS and 450 ppm zinc which was statistically similar with the application of 180 kg ha^{-1} NPS with 225 and 675 ppm zinc and 270 kg ha^{-1} NPS and 675 ppm zinc whereas the lowest tuber starch content (9.42%) was recorded from the control treatment. The combined application of 180 kg ha^{-1} of NPS and 450 ppm zinc fertilizer increased tuber starch content by 79.62 and 9.44% as compared to the control treatment and 180 kg ha^{-1} NPS fertilizer application, respectively (Table 9).The increase in starch content in response to the application of NPS and Zinc fertilizer could be attributed to enhanced growth and development as well as better photo assimilation due to high nutrient uptake.

In line with this, Debebe (2023) and Mekuannet *et al*. (2022) demonstrated that the highest tuber starch content was obtained from the application of 200 kg ha^{-1} NPS fertilizer. On the other hand, the smallest tuber starch content was obtained from the control treatment. Jafer (2023) and Feysel (2020) also reported that the highest tuber starch content was registered from 150 kg ha^{-1} NPS fertilizer whereas the lowest tuber starch content was obtained from the control treatment.

Ahmed *et al*. (2011) indicated that the highest starch content of potato tubers was obtained from the highest foliar application of zinc at a rate of 300 ppm whereas the lowest starch content of tuber was recorded from the control treatment.

Table 9. Effect of blended NPS and Zinc fertilizer rates on tuber quality related traits of potato at Debre Derhan during 2023 cropping season.

Fertilizer rates		Tuber quality related traits (%)		
NPS (kg ha^{-1})	Zinc (ppm)	Tuber dry Matter (%)	Specific Gravity (gcm^{-3})	Tuber starch Content (%)
0	0	18.68^{h}	1.058^{i}	9.42^{i}
	225	23.77^{g}	1.066^{h}	10.95^{h}
	450	24.75^{d-f}	1.069^{h}	11.61^{h}
	675	24.1^{fg}	1.072^{gh}	12.21^{gh}
90	0	23.82^{fg}	1.072^{gh}	12.14^{gh}
	225	23.95^{fg}	1.077^{fg}	13.14^{fg}
	450	24.49^{e-g}	1.08^{ef}	13.74^{ef}
	675	25.38^{cd}	1.084^{de}	14.53^{de}
180	0	24.33^{fg}	1.088^{b-d}	15.46^{b-d}
	225	25.35^{cd}	1.091^{a-c}	15.93^{a-c}
	450	28.04^{a}	1.096^{a}	16.92^{a}
	675	26.46^{b}	1.092^{ab}	16.26^{ab}
270	0	24.13^{fg}	1.083^{de}	14.47^{de}
	225	25.16^{c-e}	1.085^{c-e}	14.87^{c-e}
	450	25.70^{c}	1.088^{b-d}	15.46^{b-d}
	675	26.51^{b}	1.090^{a-c}	15.86^{a-c}
DMRT(significance)		***	***	***
CV (%)		1.75	0.33	5.07

Mean values sharing the same letter in each column are not significantly different at 5 % probability level. CV (%) = Coefficient of variation.

4.6. Partial budget analysis

The results of partial budget analysis revealed that the combined application of 180 kg ha^{-1} NPS and 450 ppm Zn provided the highest net benefit of 1,122,300 ETB ha^{-1} with acceptable marginal rate of return 3304.35% which generated (Birr 684,360 ha^{-1}) more as compared to the control treatment (Table 10). Based on this result, 180 kg ha^{-1} NPS and 450 ppm Zn resulted in the highest adjustable marketable tuber yield 38.205 t ha^{-1} which is recommended for profitable products to the farmers in the study area.

Table 10. Summary of partial budget and marginal rate of return analysis for response of potato production to NPS and Zinc fertilizer rate.

Treatments		Variables					
NPS * kg ha^{-1}	Zinc ppm	AVMY t ha^{-1}	AdMY t ha^{-1}	GFB (ETB/ ha)	TVC (ETB/ ha)	NB (ETB/ ha)	MRR (%)
0	0	16.22	14.598	437940	0	437940	-
	225	21.89	19.701	591030	4140	586890	3597.83
	450	27.33	24.597	737910	8280	729630	3447.83
	675	30.73	27.657	829710	12420	817290	2117.39
90	0	25.41	22.869	686070	7785	678285	2999.03
	225	27.89	25.101	753030	11925	741105	1517.39
	450	31.85	28.665	859950	16065	843885	2482.61
	675	33.33	29.997	899910	20205	879705	D
180	0	33.45	30.105	903150	15570	887580	-8827.27
	225	37.23	33.507	1005210	19710	985500	2365.22
	450	42.45	38.205	1146150	23850	1122300	3304.35
	675	40.41	36.369	1091070	27990	1063080	-1430.43
270	0	33.01	29.709	891270	23355	867915	D
	225	34.13	30.717	921510	27495	894015	D
	450	38.93	35.037	1051110	31635	1019475	D
	675	33.91	30.519	915570	35775	879795	D

NPS kg ha^{-1}= blended fertilizer containing Nitrogen, Phosphorus and Sulfur, Zinc ppm =, MY t ha^{-1} = Marketable yield, AdMY t ha^{-1} = Adjusted marketable yield, GFB (ETB/ ha) = Gross field benefit, TVC (ETB/ ha) = Total variable cost, NB (ETB/ ha) = Net benefit, D = dominated and MRR (%) = marginal rate return. selling price of potato at farm gate = 30 ETB kg^{-1}; purchasing costs of NPS fertilizer = 36.5 ETB kg^{-1} ; cost of Zn = 1600 ETB kg^{-1}; labor cost for fertilizer application = 500 ETB per man day.

4.7. Correlation analysis

The correlation analysis was performed to determine a simple correlation coefficient between phenological, growth, yield, yield components and quality parameters as a result of applied NPS and Zinc fertilizer. Plant height was significantly and positively correlated with days to 50% flowering (r=0.59$^{***)}$, days to physiological maturity (r=0.58***), main stem number (r=0.86***) and number of branches (r = 0.86***) (Table 11). This might be due to increasing the level both NPS and Zinc application increased in plant height, which brings increment in the number of branch and main stem number and the increase in the size of plant parts resulted in staying as vegetative which brings an extended day to flowering and maturity.

Marketable tuber yield increment was found to be strongly and positively associated with main stem number (r =0.82***), plant height (r = 0.78***), number of branches (r = 0.66***), days to maturity (r=0.53***), average tuber weight (r= 0.85***) and marketable tuber number (r = 0.73***) (Table 11).This might be due to the increase in main stem number leads to an increment in the number of branches which results in increase in the number of profuse leaves this advocate extended days to physiological maturity.

Total tuber yield increment was found to be strongly and positively related with plant height (r=0.77***), main stem number(r=0.81***), days to maturity(r=0.53***), average tuber weight (r=0.84***), total tuber number per plant (r=0.71***), marketable tuber yield (r=0.99***) and marketable tuber number per plant (r=0.71***). The possible reason for the observed association between total tuber yield and those parameters could be as Nitrogen, Phosphorus, Sulfur, zinc and other important nutrients increased in the soil due to NPS fertilizers. The soil would be more fertile and plants get sufficient nutrients, produce more leaf numbers and more vigorous growth as well as produce more photosynthesis, produce sufficient carbohydrates to increase the yield of potato. This results are in line with Zelalem Ayichew *et al*. (2009) who reported that total tuber yield was strongly associated with average tuber weight and total tuber number signifying that the increase in both tuber number and size substantially contributed to increased tuber yields.

Concerning the tuber quality, specific gravity is highly significantly ($p < 0.001$) and positively associated with average tuber weight (r=0.91***), marketable tuber number (r=0.8***), marketable tuber yield (r=0.86***), and total tuber yield (r=0.85***). Likewise, dry matter content was also highly significantly and positively correlated with average tuber weight (r=0.73***), total tuber number (r=0.71***), marketable tuber number (r=0.71***), marketable tuber yield ($r=0.81^{***}$) and total tuber yield ($r=0.81^{***}$). According to Amir Najm *et al*. (2010), the increase in the NPS fertilizer might have enhanced chlorophyll concentration, the photosynthetic rates, the leaf expansion, the total number of leaves and finally the dry matter accumulation.

Table 11. Correlation analysis of phenological, growth, yield, yield components and quality parameters of potato as affected by application of NPS and Zinc fertilizers.

PARA	DE	DF	DM	MSN	ANB	PHT	ATW	MTN	UTN	TTN	MTY	UNTY	TTY	LTS	MTS	STS	TDM	SPG	TSC
DE	1																		
DF	0.189	1																	
DM	0.37	0.432**	1																
MSN	0.351	0.372**	0.579***	1															
ANB	0.329	0.633***	0.528***	0.632***	1														
PHT	0.334	0.59***	0.584***	0.862***	0.859***	1													
ATW	0.251	0.265^{ns}	0.326*	0.876***	0.611***	0.802***	1												
MTN	0.263	0.671***	0.530***	0.744***	0.861***	0.913***	0.710***	1											
UTN	-0.230	-0.432**	-0.3189*	-0.345*	-0.503**	-0.483**	-0.332*	-0.604***	1										
TTN	0.248	0.659***	0.525***	0.756****	0.855***	0.916***	0.721***	0.989***	-0.482**	1									
MTY	0.242	0.335*	0. 0.525***	0.817***	0.656***	0.776***	0.845***	0.729***	-0.377**	0.733***	1								
UNTY	-0.005	-0.25^{ns}	-0.133^{ns}	-0.345*	-0.234^{ns}	-0.326*	-0.359*	-0.395**	0.257^{ns}	-0.388**	- 0.411**	1							
TTY	0.254	0.315*	0.532***	0.807***	0.655***	0.768***	0.835***	0.708***	- 0.358*	0.713***	0.990***	-0.28^{ns}	1						
LTS	0.296	0.517**	0.538***	0.831***	0.779***	0.854***	0.866***	0.834***	-0.423**	0.84***	0.882***	-0.471**	0.857***	1					
MTS	0.138	0.419**	0.373**	0.672***	0.635***	0.719***	0.721***	0.682***	-0.449**	0.668***	0.752***	-0.470**	0.72***	0.849***	1				
STS	-0.25	-0.500**	-0.497**	-0.816***	-0.756***	-0.836***	-0.846***	-0.809***	0.448**	-0.808***	-0.867***	0.489**	-0.838***	-0.982***	-0.934***	1			
TDM	0.295	0.447**	0.499**	0.743***	0.674***	0.715***	0.732***	0.709***	-0.364*	0.714***	0.808***	-0.294*	0.806***	0.846***	0.792***	-0.857***	1		
SPG	0.308	0.418**	0.492**	0.920***	0.713***	0.875***	0.906***	0.797***	-0.342*	0.814***	0.862***	-0.379**	0.850***	0.885***	0.719***	-0.857***	0.768***	1	
TSC	0.308	0.418**	0.492**	0.920***	0.713^{ns}	0.875***	0.906***	0.797***	-0.342*	0.814***	0.862***	-0.379**	0.850***	0.885***	0.719***	-0.857***	0.768***	1.00***	1

Where: PAR=parameter, DE=days to 50% emergency, DF=days to 50% flowering, DM=days to 75% physiological maturity, MSN=main stem number palnt^{-1}, NOB=number of branch plant^{-1}, PH=plant height (cm), ATW=average tuber weight (g/tuber),MTN=marketable tuber number plant^{-1},UNTN=unmarketable tuber number plant^{-1} ,TTN = total tuber number plant^{-1}, MTY=marketable tuber yield(t ha^{-1}),UNTY=unmarketable tuber yield (t ha^{-1}),TTY=total tuber yield (t ha^{-1}) ,DM=dry matter of tuber (%), SG=specific gravity (g/m^{3}) , SC=starch content of tuber (g/100g), *** significant at $P \leq 0.001$ probability level, ** = significant at $P \leq 0.01$ probability level, * = significant at $P \leq 0.05$ probability level and ns = non-significant probability level.

5. SUMMARY AND CONCLUSION

Potato (*Solanum tuberosum* L.) is one of the most widely cultivated vegetable crops in the highlands of Ethiopia including Debre Berhan. Farmers in the study area produce potato both as food and cash crop under irrigation and rain fed conditions. The existing potato productivity in Debre Berhan is very low despite the high potential for increased production and yield of the crop. This is due to constraints such as increasing cost of fertilizer, a few trends of farmers using poor agronomic practice, poor soil fertility, poor cultural practices, diseases and pests are the critical problems observed in most farmers' field. Thus, to improve the production and productivity of the crop, soil fertility management has to be the primary role of the producers.

Therefore, a study was conducted to investigate the effect of NPS fertilizer and zinc on growth, yield, yield components and quality of potato (*Solanum tuberosum* L.) at Debre Berhan, North Shewa, Ethiopia. The experiment was carried out with four levels of NPS (0, 90, 180 and 270 kg ha^{-1}) and four levels of zinc (0, 225, 450 and 675 ppm) in 4 x 4 factorial arrangement laid out in randomized complete block design with three replications and ''Belete" potato was used as experimental material. The combined application of 270 kg ha^{-1} blended NPS fertilizer and 450 ppm zinc resulted in the highest main stem number (6.03), plant height (81.83 cm) and number of branches (16.00).On the other hand the combined application of 180 kg ha^{-1} NPS fertilizer and 450 ppm zinc resulted in the highest average tuber weight (88.60g $tuber^{-1}$), marketable tuber number per plant (20.13), total tuber number (23.54), marketable tuber yield (42.45 t ha^{-1}), total tuber yield (46.06 t ha^{-1}), tuber dry matter (28.04), specific gravity (1.096) and tuber starch content (1.096).

The partial budget analysis revealed that the application of 180 kg ha^{-1} NPS and 450 ppm Zn resulted in the highest net benefit of (1,122,300 ETB ha^{-1}) with the acceptable marginal rate of return (3304.35%) which generated (Birr 684,360 ha^{-1}) more as compared to the control treatment. Hence, for economical potato production in the study area and similar agro-ecologies, it is advisable to apply 180 kg NPS ha^{-1} and 450 ppm Zn fertilizer. However, as the results are limited to one season and location, further study should be done in the study area and also in different locations and seasons to establish the conclusive recommendations so as to improve the production and productivity of potato in the study area.

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7. APPENDICES

Appendix Table 1. Mean squares of analysis of variance for the effect of blended NPS and Zinc fertilizers on growth, yield, yield components and quality parameters of potato at Debre Berhan during 2023 cropping season.

Parameters/source	Block	NPS	Zinc	NPS*Zinc	error
df	2	3	3	9	30
DE	0.02	0.81^{ns}	0.14^{ns}	0.84^{ns}	0.61
DF	4.52	3.91^{**}	1.91^{ns}	1.29^{ns}	0.79
DM	2.44	4.69^{*}	2.92^{ns}	1.91^{ns}	1.23
MSN	2.91	16.04^{***}	1.60^{**}	3.66^{***}	0.32
NOB	16.78	99.03^{***}	20.05^{***}	25.67^{***}	2.07
PHT	2.41	650.55^{***}	34.16^{***}	139.05^{***}	2.77
ATW	131.68	$677.02^{** *}$	80.43^{**}	$161.29^{** *}$	16.02
MTN	46.69	292.96^{***}	34.05^{***}	66.94^{***}	3.91
UNMTN	0.65	2.53^{**}	0.46^{ns}	0.83^{ns}	0.55
TTN	37.07	242.26^{***}	29.07^{***}	55.39^{***}	3.17
MTY	1.53	553.11^{***}	42.23^{***}	130.73^{***}	5.57
UNMTY	6.51	5.51^{**}	0.35^{ns}	4.82^{ns}	0.84
TTY	12.56	398.95^{***}	27.72^{**}	92.06^{***}	4.32
LTS	0.54	412.65^{***}	94.60^{***}	110.17^{***}	3.61
MTS	2.73	100.88^{***}	22.82^{***}	28.78^{***}	2.55
STS	5.11	904.58^{***}	188.5^{***}	238.59^{***}	9.26
DM	0.2	23.42^{***}	23.14^{***}	11.78^{***}	1.05
SG	0.00	0.0015^{***}	0.0002^{***}	0.00035^{***}	0.00002
SC	5.28	60.04^{***}	8.11^{***}	13.94^{***}	0.73

Where, df=degree of freedom, DE=days to 50% emergency, DF=days to 50% flowering, DM=days to 75%physiological maturity, MSN=main stem numberpalnt^{-1}, NOB=number of branch plant^{-1}, PHT=plant height (cm), ATW=average tuber weight (g/tuber) MTN=marketable tuber number plant^{-1} ,UNMTN=unmarketable tuber number plant^{-1},TTN=total tuber number plant^{-1}, MTY=marketable tuber yield (tha^{1}),UNMTY=unmarketable tuber yield (tha^{-1}), TTY=total tuber yield (tha^{-1}) ,LTS=large tuber size, MTS=medium tuber size, STS=small tuber size, DM=dry matter of tuber (%), SG=specific gravity (g/cm^{3}), SC=starch content of tuber (%),***= significant at P ≤ 0.001 probability level,**= significant at P ≤ 0.01 probability level, * = significant at P ≤ 0.05 probability level and ns = non-significant at P > 0.05 probability level.

Appendix Table 2. The main effect of blended NPS and Zinc fertilizers on growth parameters of potato at Debre Berhan during 2023 cropping season.

NPS (kg ha^{-1})	PHT	MSN	ANB
270	79.32^{a}	5.57^{a}	14.03^{a}
180	78.97^{a}	5.36^{a}	13.90^{a}
90	69.99^{b}	4.13^{b}	10.18^{b}
0	64.17^{c}	3.08^{c}	8.20^{c}
CV	2.27	12.37	12.42
Zn (ppm)			
675	74.28^{a}	4.83^{a}	12.52^{a}
450	74.78^{a}	4.80^{a}	12.67^{a}
225	72.16^{b}	4.46^{ab}	11.64^{a}
0	71.24^{b}	4.05^{b}	9.74^{b}
CV (%)	2.27	12.37	12.42

Where: PHT = plant height (cm), MSN= stem number plant^{-1}, ANB= average number of branch plant^{-1}, Values connected by a different letter across a column are significantly different at the 5% significance level.

Appendix Table 3.The main effect of blended NPS and zinc fertilizers on yield and yield component parameters of potato at Debre Berhan during 2023 cropping season.

NPS (kg ha^{-1})	MTN	TTN	ATW	MTY	TTY
270	17.30^{a}	21.72^{a}	80.11^{a}	34.995^{b}	40.41^{a}
180	17.53^{a}	21.64^{a}	79.34^{ab}	38.39^{a}	42.55^{a}
90	10.86^{b}	15.85^{b}	76.24^{bc}	29.62^{c}	35.10^{b}
0	7.52^{c}	12.62^{c}	74.61^{c}	24.04^{d}	29.66^{c}
CV	14.86	9.91	5.16	11.22	9.45
Zn (ppm)					
675	14.69^{a}	19.39^{a}	79.94^{a}	34.6^{a}	39.77^{a}
450	14.74^{a}	19.10^{a}	79.67 ^{a}	35.14^{a}	40.22^{a}
225	12.41^{b}	17.19^{b}	77.15^{ab}	30.29^{b}	35.70^{b}
0	11.37^{b}	16.14^{b}	75.40^{b}	27.02^{c}	32.05^{c}
CV	14.86	9.91	5.16	11.22	9.45

Where: MTN=Marketable tuber number plant^{-1}, TTN= Total tuber number plant^{-1}, ATW= Average tuber weight (g plant^{-1}), MTY=Marketable tuber yield (t ha^{-1}), TTY=Total tuber yield (t ha^{-1}), Values connected by the different letter across a column are significantly different at the 5% significance level.

Appendix Table 4. The main effect of blended NPS and zinc fertilizers on tubers size categories and tuber quality related parameters of potato at Debre Berhan during 2023 cropping season.

NPS (kg ha^{-1})	STS	MTS	LTS	TDM	SPG	TSC
270	17.3^{c}	39.40^{b}	43.30^{b}	25.37^{a}	1.087^{b}	15.16^{b}
180	8.81^{d}	42.61^{a}	48.58^{a}	26.04^{a}	1.092^{a}	16.14^{a}
90	23.91^{b}	36.67^{c}	39.42^{c}	24.41^{b}	1.078^{c}	13.39^{c}
0	28.87^{a}	36.39^{c}	34.76^{d}	22.82^{c}	1.066^{d}	11.05^{d}
CV	15.43	4.12	4.58	4.15	0.4	6.15
Zn (ppm)						
675	17.52^{c}	38.66^{b}	43.83^{a}	25.61^{a}	1.084^{a}	14.72^{a}
450	15.99^{c}	40.25^{a}	43.75^{a}	25.74^{a}	1.083^{a}	14.43^{a}
225	20.37^{b}	39.2^{ab}	40.43^{b}	24.56^{b}	1.08^{b}	13.72^{b}
0	25.01^{a}	36.95^{c}	38.03^{c}	22.74^{c}	1.075^{c}	12.87^{c}
CV	15.43	4.12	4.58	4.15	0.4	6.15

Where: STS=Small tuber size, MTS= Medium tuber size, LTS= Large tuber size, TDM=Tuber dry matter content, SPG=Specific gravity, TSC=Tuber starch content, Values connected by the different letter across a column are significantly different at the 5% significance level.