EFFECT OF INTER ROW SPACING ON GROWTH, YIELD AND TUBER QUALITY OF POTATO (*Solanum tuberosum L.)* VARIETIES IN HADIYA ZONE, SOUTHERN, ETHIOPIA

MSc. THESIS

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A THESIS SUBMITTED TO THE SCHOOL OF PLANT AND HORTICULTURAL SCIENCES, HAWASSA COLLEGE OF AGRICULTURE, SCHOOL OF GRADUATE STUDIES HAWASSA UNIVERSITY HAWASSA, ETHIOPIA

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We, the undersigned, members of the Board of Examiners of the final open defense by Mulugeta Sodano Lantero have read and evaluated his thesis entitled "Effect of inter row spacing on growth, yield and tuber quality of potato *(Solanum tuberosum L.)* Varieties in Hadiya zone, southern, 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 Master's.

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STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this thesis is a genuine result of my work. I have duly followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of this thesis. Any scholarly matter that is included in the thesis has been given recognition through citation. This thesis is submitted in partial fulfillment of the requirements for the Degree of Master of Science in horticulture at Hawassa University. The thesis is deposited in the library of the Hawassa University and is made available to borrowers under the rules and regulations of the library. I solemnly declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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DEDICATION

This thesis manuscript is dedicated to my beloved family.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CIP	International Potato Centre
FTC	Farmers Training Centers
HARC	Holetta Agricultural Research Centre
HURC	Haramaya University Rare Research Centre
HZMBD	Hadiya Zone Misrak Badwacho District
ISSD	Integrated Seed Sector Development
KARI	Kenya Agricultural Research Institute
LSB	Local Seed Business
LSD	Least Significant Difference
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
NARO	National Agricultural Research Organization
NPSB	Nitrogen Phosphorus Sulfur Boron
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis Software
SPCS	Seed Producer Cooperatives

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ABSTRACT

Potato is the very important food and cash crop in Ethiopia, especially in the high and mid altitude areas. It is important to select better yielding potato varieties with appropriate plant density per unit of area to get for better yield and tuber quality in given location. This experiment was conducted to determine proper inter row spacing for potato varieties and to select better performing potato variety at Hadiya zone Misrak Badewaccho district, during the year 2022 G.C main cropping season. The experiment was arranged in a factorial combination of three inter row spacing (70 x 30 cm, 60 x 30 cm and 50 x 30 cm) and five potato varieties (Gudane, Zemen, Belete Jalene and local) in a randomized complete block design (RCBD) with three replications. The result revealed that days to 50% emergence and stem number per hill were significantly affected by variety, days to 90% maturity, plant height, leaf number per plant, leaf area index, harvest index, total biomass, total tuber yield, tuber number per hill and tuber size distribution were significantly affected by main factors (variety and inter row spacing) but not by interaction. Days to 50% flowering, leaf area, marketable tuber yield, unmarketable tuber yield, marketable tuber number, unmarketable tuber number, dry matter, total starch content and specific gravity were significantly influenced by main factors (variety and inter row spacing and interaction). The highest, stem number per hill, plant height, leaf number per plant, leaf area, leaf area index, harvest index, total dry biomass, total tuber yield, tuber number per hill, marketable tuber yield, marketable tuber number dry matter and specific gravity was scored from Gudene variety whereas, lowest data was recorded from local variety. The highest stem number per hill, plant height, leaf number per plant, leaf area, total dry biomass, tuber number per hill, specific gravity and total starch content recorded at inter row spacing (70 x 30) cm. The highest interactive effect was scored from marketable tuber yield from Gudene (36.00t/ha^{-1}) and Belete (34.67t/ha^{-1}) variety and at inter row spacing (60 x 30 cm) whereas, lowest interactive effect was recorded from local (12.83t/ha^{-1}) variety and at inter row spacing (50 x 30 cm). Therefore, from this study, it can be concluded that Gudene and Belete varieties at inter row spacing (60 x 30cm and 70 x 30cm) resulted in highest marketable potato yield. The results obtained in this study are based conducted at single season and single location it should be repeated to validate this result before recommending to the area.

Keyword: *Potato, variety, inter row spacing, yield.*

1. INTRODUCTION

1.1 Background

Potato (*Solanum tuberosum L*.) is the fourth most important food crop in consumption in the world after rice; wheat and maize (Tkachenko *et al*., 2021; Zhang *et al*., 2017). Potato is an annual herbaceous and dicotyledonous plant that belongs to the Solanaceae family. Solanaceae includes such plants as tobacco, tomato, eggplant, chili pepper, horse nettle, bittersweet nightshade, ground cherry, and petunia (Viola *et al*., 2007). Potato was first domesticated in the area around Lake Titicaca, which is located 3800 meters above sea level on the border of modern-day, Bolivia and Peru, in the Andes mountain range of South America (Asfaw *et al.*, 2016). It is one of an important food and cash crop in eastern and central Africa, playing a major role in national food security and nutrition, poverty alleviation and income generation and provides employment in the production, processing and marketing sub-sectors (Wassihun *et al*., 2019; Lung'aho *et al.*, 2007). According to Kolech (2019) potato is considered as a food safety crop that helps to meet the increasing food stress in the tropical highlands of Sub-Saharan Africa. Nutritionally, potato tubers are an excellent source of energy from its carbohydrates, calories, rich in minerals and vitamins and also present high quality protein. The crop contains 79% water, 17% carbohydrates, 2% protein, and free from fat and also raw potato gives 77 calories of energy and a rich source of Vitamin B6 and Vitamin C (Melito *et al.*, 2017; Sriom *et al*., 2017).

Potato is cultivated in 245 countries in the tropical, subtropical and temperate zones of the world (FAOSTAT, 2020). Major potato producer's countries in the world are China, India, Russia, Ukraine and United States (FAOSTAT, 2021). Total area coverage of potato in the world exceeding 22.6 million hectares of land giving an estimated annual production of 403.5 million tons and its average productivity is 21 tons ha^{-1} (FAOSTAT, 2021). In Africa`s total area coverage of potato 1.76 million hectares and production is about 26.5 million tones. The average productivity of potato in Africa is 13 tons ha^{-1} which is much lower than the amount produced in the world (FAOSTAT, 2020).

Potato was introduced to Ethiopia in 1858 by the German botanist Wilhelm Schimper (Lemaga *et al.,* 1992). About 0.93 million tons of potatoes are produced from 0.736 million hectares and average productivity is national 13.9 t/ ha^{-1} (FAOSTAT, 2020). Among root and tuber crops in Ethiopia, potato ranks first in volume produced followed by cassava (*Manihot esculenta Crantz*), sweet potato (*Ipomoea Batatas L. Lam*], and yam (*Dioscorea spp*), (Wassihun *et al*., 2019). Ethiopia has a huge potential for the production of the potato because about 70% of arable land in the country found in the altitudes ranging from 1,500 - 3,000 meters above sea level and annual precipitation of 600-1,200 millimeters (Egata, 2019; Gebremedhin *et al.*, 2008).

In Ethiopia, potato is amongst the majority economically significant crops on the basis of food sources and cash in the country (Wassihun *et al*., 2019). Potato production has been considered as the first priority compared to other food crops because of its contribution to food security, income generation and double cropping advantages and its utilization in different forms (Lung'aho *et al*., 2007). In Ethiopia, potato is grown in four major areas: the central, the eastern, the northwestern and the southern. Together, they cover approximately 83% of the potato farmers (FAOSTAT, 2021). A brief description of each area is as follows: In this area the major potato growing zones are West and North Shewa. About 21% of the potato farmers are located in this area (FAOSTAT, 2020). Average productivity of a potato crop ranges from 8 to 10 t/ ha^{-1} which are higher than the productivity in the northwestern and southern areas. This higher productivity might be due to the use of improved varieties and practices obtained from Holetta Agricultural Research Centre in the central area. In the central area potato is produced mainly in the belg (short rain season from February to May) and meher (long rain season—June to October) periods.

In Amhara Region, about 395,429.45 tons of potato was produced on 29,081.48 ha^{-1} of land with a productivity of 13.6 t/ha^{-1} which is about 30% of the national potato production (CSA, 2020) it is the major potato growing area in the country, contributing for about 23% of the potato farmers (CSA, 2020). South and North Gonder, East and West Gojam and Agew Awi are the major potato production zones. Farmers mainly grow local varieties. Productivity ranges from 14.3 to 20.3 t/ ha^{-1} (FAOSTAT, 2020). In this area, the largest volume of potato is produced in the belg season followed by irrigated potato produced off-season. Potato is also produced in the meher season.

The eastern area of potato production mainly covers the eastern highlands of Ethiopia, especially the East Harerge zone. Only about 3% of the total number of potato growers is situated in this area (FAOSTAT, 2020) but the area is identified specifically because the majority of the potato farmers in this area produce for the market and there is also some export to Djibouti and Somalia. Productivity ranges from 11 to 13 t/ ha^{-1} (FAOSTAT, 2020). This season is characterized by low disease pressure and relatively high prices (Mulatu *et al*., 2005b). Potato is also produced in the belg (February to May) and the meher (June to October) seasons. Most farmers grow local potato varieties.

The southern area of Ethiopia in which potato is grown, is mainly located in the Southern Nations', Nationalities' and Peoples' Regional State (SNNPRS) and partly in the Oromiya region. The major potato producing zones in this area are Gurage, Gamo Goffa, Hadiya, Wolayta, Kambata, Siltie and Sidama in the SNNPRS and West Arsi zone in Oromiya. More than 36% of the total number of potato farmers is located in this area (FAOSTAT, 2020). Potato tubers are produced under rain fed conditions and under irrigation. Productivity ranges from 14.1 to 20.4t/ha^{-1}, whereas in some places potato productivity is even below 7t/ha^{-1}(FAOSTAT, 2020). About six varieties are grown, of which four are local and two are improved (Endale *et al*., 2008a).

The main factor for the lower production and productivity of potatoes in Ethiopia like any other crop is affected by a number of biotic and abiotic stresses (Kroschel *et al*., 2020; Demirel *et al*., 2020; Okonya *et al*., 2019; Temesgen Magule, 2008). These include lack of proper planting material, inappropriate agronomic practices and storage facilities. Limited knowledge resulting in poor seed tuber selection and inadequate good quality potato seed, shortage of high yielding varieties, post-harvest losses due to poor handling, poor seed distribution system and inadequate cultivation technologies. Drought, erratic rainfall, high temperature, frost and high disease and insect pressure. Although potato bacterial wilt is a soil-borne disease, by a lot of biotic and abiotic challenges such as unfortunate agricultural practice limitless animal and human movement to agricultural fields, be short of knowledge on suitable field hygiene events plant pathogen impure seed time to time, poor seed quarantine policy, soil acidity, and ecological differences (Tessema *et al.*, 2022; Tafesse *et al.*, 2021; Tessema *et al.*, 2020).

Optimizing plant density is one of the most important agronomic practices of potato production because it affects seed price, plant growth, yield and quality of the crop (Bussan *et al*., 2007). This result is due to increased inter-plant competition for water, light and nutrients (Masarirambi *et al*., 2012). Plant density in potato affects some important plant traits such as total yield, the quantity of marketable tuber number, unmarketable tuber number and tuber quality (Asfaw *et al.*, 2016). Variation in the plant density causes changes in the light intensity, humidity and temperature within canopies. Too close spacing interferes with normal plants growth and increase competition for moisture, mineral, nutrients, and light and hinders harvest operations consequential in yield decrease and is also alike to declining the concentration of enlargement factor while, too wider spacing may effect in too much vegetative enlargement of plant and abundant weed inhabitants due to extra feeding space obtainable. The blanket recommended plant spacing for all potato variety in Ethiopia is 75 cm by 30 cm between rows and plants, respectively (MoA, 2014; Asresie *et al*., 2015) while CASCAPE project demonstration recommended inter row spacing of 60 cm and intra row spacing of 30cm for best possible ware potato produce (Asresie *et al.,* 2015). But there are still a lot of farmers who produce potatoes often in the area giving fewer regard to best plant density for production of ware and seed potatoes however, the option of inter row spacing is not associated to the level of production alone, however in addition to the option of potato variety to be grown. Better potato varieties as one with better management is proved to give three to four fold yield advantage as compared to local variety with traditional making management practices (Arega *et al*., 2018). Factors for the lower production and productivity of potatoes in the country is credited due to short of well tailored varieties, low supply of quality seeds and high cost of seed tubers of improved varieties and depletion of soil fertility and too low or too high planting density. The low average yield is attributed to a lot of challenges, the main one being lack of well adapted high yielding variety, unavailability and high cost of quality seed tubers, inappropriate agronomic practices, diseases, insect pests, inadequate storage. The majority of potato growing smallholder farmers uses low yielding and late blight susceptible local varieties due to the limited availability of improved seed potatoes in the country especial in the study area. In many parts of Ethiopia mainly at study areas, farmers grow old varieties, which resulted in farmers for demanding of higher yielder and disease resistant varieties of potato. Thus, evaluation of potato varieties at different potential areas like Arsinegele, kabeta tembaro, and Shashemene is one of the means to solve the aforementioned problems. Therefore, the research was done to evaluate the performance of potato varieties and inter row spacing on growth, yield components and quality of potatoes and identify proper inter row spacing and marketable yield of potato varieties production.

1.2. Statement of the Problem.

Variety and plant density are amongst the most significant constraint of limited potato production in Ethiopia mainly at study areas. Many researchers recommended spacing of 75cm between rows and 30cm between plants (Asresie *et al*., 2015). In southern nation, nationality region is one of the potential arable land producing areas, it has suitable fertile soil and climatic conditions mainly in study areas. A lot of parts of Ethiopia mainly at study areas farmers complain about the old local seeds variety grow to use as a seed for economical production very lower with average productivity of 7.8 t/ha^{-1} under rain feed condition, which is very low compared to world average productivity of potato 21 t/ha^{-1} (FAOSTAT, 2021). In Ethiopia, a number of improved potato varieties have been released by different research centers and institutions (Asefa *et al*., 2016). But there are still a lot of parts of country mainly at study areas farmers who produce potatoes often in the area giving fewer regard to best plant density and variety for production of ware and seed potatoes. Too low or too high plant density, old seed potato variety and most of farmers are following traditional practices of potato production systems are some of the major problems accounting for the low marketable tuber yield of the potato variety. Hence, potato production and productivity is very low a lot of parts of country including the study areas. So far there is no study and suggestion within improved variety and inter row spacing in the study area. Therefore, the present study was conducted with the following objective

1.3. Objectives of the Study

1.3.1. General Objective

- To evaluate the effect of inter row spacing on growth, yield and quality of potato varieties at Hadiya zone, southern Ethiopia.

1.3.2. Specific Objectives

- To identify potato varieties with optimum growth and yield component
- To determine the optimum inter row spacing for growth, yield and quality components of potato varieties
- To investigate the interaction effects of inter row spacing and potato varieties on its growth, yield and quality related parameters of potato

2. LITERATURE REVIEW

2.1. Ecology of Potato Crop

2.1.1. Temperature

Temperature has influential effects on the tuberization stimulus (Emana and Nigusse, 2011) pointed out that potato is best adapted to cool climates such as tropical highlands with mean daily temperatures between 5 and 18^{0}c as encounter in its center of origin. Elevated temperatures good turn foliar development and slow down tuberization. In addition, heat stress leads to a higher number of smaller tubers per plant; lower tuber specific gravity with reduced dry matter content, and usually to a paler skin color of the tubers. (Vreugdenhil, 2007) who reported that the highest relative growth rate of potato obtained at low temperature and low irradiance. They further explained; high temperature and low irradiance combination had the opposite effect, producing the lowest net assimilation and relative growth rates. Both tuber number and weight were markedly decrease by high temperature. Low irradiance in combination with high temperature produced almost no tubers. The rate of development of sprouts days to emergence depends on soil temperature.

According to (Vreugdenhil, 2007) stated that emergence was linearly related to mean soil temperature and relatively independent of diurnal fluctuations up to an optimum of 22-24^{0}c and emergence was inhibited above this optimum level. The author also reviewed studies on the effect of 20^{0}c and 30^{0}c root zone temperatures on root growth and root morphology of six potato clones and reported significant genotypic differences in the responses of potato roots to 30^{0}c were observed, indicating the potential for selecting heat tolerant potato clones. In both heat tolerant and heat sensitive clones, the size of the root system was reduced by a 30^{0}c root zone temperature explained by a reduction in the cell division followed by a cessation of root elongation.

Tuberization motivation favors both tuber initiation and tuber enlargement. The optimum soil temperature for initiating tubers ranges from 16 to 19^{0}c (Western Potato Council, 2003). Tuber development declines as soil temperatures rise above 20^{0}c and tuber growth practically stops at soil temperatures above 30^{0}c. The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favor development of large tubers (Western Potato Council, 2003). (Ewing and Struik, 1992) who reported that in many areas the sequence of temperatures that most often brings economic damage to potato crops is warm temperatures early in the season, followed by cool temperatures that encourage strong tuberization, followed in turn by another phase of high temperatures.

2.1.2. Moisture

Potato tuber response to soil moisture conditions begins before tuber set (MacKerron and Jefferies, 1986) have shown that increased duration of water stress before tuber initiation decreases tuber set per stem. Where Verticillium wilt is present, there are advantages to keeping soils a little dry early in the season before tuber initiation (Eldredge *et al.,* 1996). According to (Kleinkopf, 1979) found that 'Russet Burbank' was more sensitive than the 'Butte' variety in forming misshapen tubers under water stress fluctuations in water that stress the potato plant during tuber development can be result in greater proportions of distorted tubers of lower market grade. According to (Pereira and Villa Nova, 2002) studied the effect of three irrigation treatments on tuber yield and grade and reported that fully irrigated potatoes had higher yields, better grade and fewer physiological defects. Tuber physiological disorders such as brown center, hollow heart, and translucent end, as well as secondary growth, growth cracks, bruise susceptibility, and heat necrosis have been associated with water stress and/or wide variations in soil moisture content (Eldredge *et al.,* 1996).

Wet soil is conducive to most tuber-rotting pathogens and excessive soil moisture following planting can promote seed piece decay and erratic plant. Excess soil moisture also encourages the incidence of blights, rots, and wilts, particularly prolonged excess soil water conditions. Therefore, avoiding over-irrigation, or even keeping soils a little dry early in the season before tuber initiation may reduce the amount of root infection. Well drained, fertile loamy sand, sandy loam soil rich in organic matter and deep friable good water retaining capacity with pH 5-5.5 is suitable for optimum production potato and adequate moisture is required for stable growth and maximum yield of potato (Tesfaye, 2007). One of the most ecological threats to global agriculture is salinity of soils and it leads to an imbalance in plant physiological processes and also impact the quality and production of potatoes in mainly semi-arid growing areas (Ahmed *et al*., 2020). However, potato is moderately sensitive to soil salinity and also cannot tolerate alkaline soil, yield decreased with increasing soil salinity (Charfeddine *et al*., 2019).

2.2. Effect of Inter Row Spacing on Potato Growth

Potato is serious nutrient feeder crop and the nutrients have a significant function in improvement of yield and quality of vegetable crops. Inter and intra row spacing is a vital factor determining potato yield and component. Inter and intra row spacing should depend on type of variety, fertility status of soil, plant architecture or growth habit etc. (Taye *et al*, 2021; Girma and Niguisse, 2015). Inter and intra row spacing was significantly affected the growth parameters of potatoes including days 50% flowering, plant height, and maturity (Tesfaye *et al*., 2012). Many researchers reported that the availability of wider plant spacing enhances the height of the plants by reducing competition of different growth factors like nutrients, water, and sunlight (Bikila *et al*., 2014; Endale and Gebremedhin, 2001). According to (Tesfaye *et al*., 2012) also the research indicated that the earliest days to 50% flowering at the closer inter row spacing of 40 and 50 cm whereas days of 50% flowering was prolonged in 60 and 75 cm inter row spacing and also maturity was influenced by inter row spacing when an increase of plant density shortened days to maturity which can be associated with inter plant competition, and probably depletion of available nutrient and hence stressed plants tend to senesce earlier. A closer inter row spacing, there is the high number of plants per unit area which brings about an increased ground cover consequently influencing photosynthesis (Harnet *et al*., 2014).

According to (Zebenay, 2015) reports plants grown at wider inter row spacing of 75 cm to have the highest plant height than plants grown at the closer inter row spacing of 40 cm. This may be due to better availability of nutrients, water and sunlight whereas plants are grown in wider inter row spacing have less competition and grow more shoot. Similarly, (Bikila *et al*., 2014) studied that the tallest plant height was recorded when intra row spacing increases from 20 to 40cm whereas densely populated plants show intensive competition which leads to decrease in plant height. (Tesfaye *et al*., 2012) also observed that in days to maturity were affected highly and significantly by intra row spacing. The result indicated that earliest days of maturity were observed at the closer intra row spacing of 40cm but it was extended at the wider intra row spacing of 70 cm. This might be due to the presence of intense interplant competition that leads to depletion of the available nutrient as a result plants could be stressed and tend to mature earlier.

2.3. Effect of Inter Row Spacing on Potato Yield

The optimizing of plant density is one of the most important subjects of potato production management, because it affects seed cost, plant development, yield, and quality of the crop (Bussan *et al.,* 2007). Plant density in potato affects some of the important plant traits such as total yield, tuber size distribution and quality (Zabhi *et al.*, 2011). According to (Gregorious, 2000) planted seed tubers within-row spacing of 10, 20, 30 or 40 cm and reported that seedling emergence was reduced at 10 cm spacing. The author further reported that tuber yield decreased with increasing spacing. The best combination of total potato yield was estimated to be with a 30 cm planting distance. According to (Yenagi *et al.*, 2004) in 1995 and 1996 to determine optimum spacing for the potato variety, Awash, Menagesha and Tolcha and reported that there were significant varietal and spacing effects on seed tuber size, average tuber weight and number per square meter. In-row spacing regulated tuber weight more than yield. The variety showed different requirements for spacing for the development of optimum leaf area and maximum tuber number and yield.

According to (Rahemi *et al*., 2005) also reported that intra row spacing significant result on the yield of potatoes, where intra row spacing 20cm showed 36.85% yield increase as compared to 30cm intra row spacing. According to (Semir and Bikila, 2018) consequences the maximum number of tuber per plant (10.93) was recorded from the wider intra row spacing 40cm whereas the lowest number of tuber per plant (6.72) was recorded at closer intra row spacing 10cm. At the wider intra row spacing there is least competition among plants for resource and this effect which enlarged number of tuber per plant (Tesfaye *et al*., 2013). These authors also reported that the maximum marketable yield was recorded at the wider intra row spacing of 30cm, whereas the humble was obtained at the closer intra row spacing of 10cm. This increase is due to their photosynthesis efficiency for elevated photo assimilation production and ultimately resulted in increased extra marketable tuber yield (Tesfaye *et al*., 2013).

According to (Ahire *et al.*, 2000) at Rahuri, Maharashtra, India, during the rabi season of 1996-97. Treatments consisted of 2 inter row spacing (60 and 45 cm), 2 planting systems (normal and paired row) and 2 irrigation methods (trickle and surface). The authors reported that the wider inter row spacing of 60 cm increased plant growth and tuber yield (20.29 t /ha^{-1}) compared with the narrow inter row spacing of 45 cm (17.86 t /ha^{-1}). The growth (plant height, number of stem per hill, leaf area and total dry matter production (leaves, stems and tubers $plant^{-1}$), yield and quality (reducing sugar content) of potato were evaluated at different intra-row spacing (60 x 15, 60 x 20 and 60 x 25 cm) and fertilizer levels by (Kumar *et al.,* 2009). The author reported that potato seed crop grown by seed tuber at a spacing of 60 × 15 cm with application of 125% of the RDF (recommended dose of fertilizer), followed by 60 × 20 cm with application of 100% of the RDF, was proved advantageous to obtain higher yield of seed-size tuber as well as total tuber yield/ha during the rainy season. Optimizing plant density and seed size are the most important subjects of potato production systems due to their effects on seed cost, plant development, yield and quality of the crop. In these relations and experiment was conducted by (Gulluoglu and Aroglu, 2009) to know the effects of different in-row spacing (20, 25, 30 and 35 cm) and seed size (small, medium and large) treatments on yield components and tuber yield of potato. The authors observed that closer inter row spacing reduced tubers per hill, average tuber weight, tuber yield per hill and percentages of large and medium weight tubers. Total yields increased as increasing planting density up to 20 cm spacing. The authors opined that seed size should be considered during recommendation for planting density in potato production.

2.4. Effect of Inter Row Spacing on Potato Tuber Quality

According to (Getachew *et al.,* 2013) found high plant density to be associated with high dry matter content. Low dry matter content at the wider inter row spacing was due to the high photosynthetic rate, thus a relatively high vegetative growth at the expense of the tubers. Dry matter partitioning to the tubers was less. Many other studies showed increased dry matter with decreasing plant density (Tefi *et al.,* 2010). Dry matter accounts for as much as 60 to 80% of the tuber dry weight and are the major storage component of tubers. Freshly harvested potatoes contain about 80%

water and 20% dry matter (Kolbe and Stefan-Beckmann, 1997). It is often essential to know the dry matter content of potato tubers since this mostly governs the weight of processed products, which can be obtained from a given weight of raw tubers. It is also one of the determinants of tuber quality, both for processing as well as cooking. High dry matter has been described to be desirable due to of less sugar content and water accumulation (Nelson and Shaw, 1976). (Storey and Davies, 1992) who have been observed that tubers with high dry matter content necessary less energy input during frying or dehydration to remove water resulted in greater product yield per unit fresh weight than tubers with lower solid content and absorbed less oil during frying. They also noted the tuber dry matter content was influenced by a wide range of factors that challenged the growth and development of the crop, including most significantly, environmental factors such as intercepted solar radiation, soil temperature, available soil moisture and cultural treatments (Storey and Davies, 1992)

According to (Tesfaye *et al.*, 2013) reported that specific gravity is the measure of option for estimating dry matter content (DMC) and starch content (SC) and finally for determining the processing quality of potato varieties. Potatoes of high dry matter contents, more typically expressed as high specific gravity, are significant in processing industry in terms of ended product yield, oil uptake and quality (Sayre *et al.*, 1975). The major carbohydrate present in tubers and root crops is starch accounting for 16-24% of their weight and remaining being water and trace quantities of proteins and lipids (<4%) (Hoover, 2001) some examples of root and tubers grown for edible purposes are: potato (*Solanum tuberosum*), sweet potato (*Ipomea batatas*), cassava (*Manihot esculenta*), etc. Starch properties are affected by the varieties and environmental factors (production area, soil, climate etc.) and based on identical, the properties differ significantly (Noda *et al.*, 2004). However, little is known about starch composition of many of the world‘s potato varieties (Food and Agriculture Organization of the United Nations, 2010). Starch comprises of two components namely a mylose and a mylopectin. While the amylose fraction is linear in structure, amylopectin is highly branched (Zobel, 1988). Amounts of these two components challenging properties like swelling capacity, water solubility; water binding capacity, mechanical properties of starch films, along with microscopic properties (Sandhu *et al*., 2005).

2.5. Effect of Potato Variety

The potential of potato growth, yield and quality is mainly determined by its genetic makeup and mostly governed by the environment (Barry *et al.*, 1990). Potato varieties have varied response to the growing environment such as soil type. (Endale *et al.*, 2005) who reported the happening of more tuber crack on Menagesha variety than Genet under vertisol condition of Ginchi and explained the difference in tuber growth cracking 11 most likely credited to the hereditary difference between the two varieties. (Ahmed *et al.,* 2000) who reported that potato varieties considerably vary in tuber yield potential and resulted in unlike amount of yield under the same agro climatic condition. Varieties that shed their leaves (early varieties) before others (late ones) maintains a higher radiation-use efficiency, and vice versa. However, in the absence of water limitation, water-efficient potato genotypes generally perform less than 'water spending' types (Vreugdenhil, 2007). (Ewing and Struik, 1992) also reported that tubers of different potato varieties vary in size, skin and flesh colour and skin texture. In Ethiopia, a number of varieties are under cultivation including those released from research centers and introduced at different times. There is no sufficient in sequence on time of introduction, origin, quality and adaptation of the introduced potato varieties (Gebremedhin *et al.,* 2001). The yield, taste and better market price are the factors that were used to select potato varieties and/or cultivars (Gebremedhin *et al.,* 2001). Some of local varieties grown in miserk badawcho district are 'Nech Abeba', 'Key Abeba', 'Agea' and ‘Durame’ which are susceptible to Phytophthora infestans and most farmers given up potato production from the main cropping season(June to September) due to the pressure of the disease.

2.6. Yield and Quality Differences of Local and Improved Potato Variety

Local varieties are reported to be generally low yielding, susceptible to disease and pests and subjected to rapid virus degeneration (Kidane-mariam, 1980). However, farmers apparently consider many factors in selecting varieties. In addition to the essential qualities of yield and resistance to disease (especially late blight), varieties are also selected for tuber traits considered positive, especially for commercial sale, relative smoothness of texture, shallow eyes, more attractive shaped (specific not provided), whiter cooler in preference to red and cooking quality (Gebremedhin *et al*.,2001). The available information suggests also that modern varieties often lack additional characters which farmers consider important. For example; the varieties can be grouped in to two parts in Bangladesh such as indigenous (local) potato varieties and modern (improved) varieties. Indigenous potato varieties are popular for good taste but low yielding and high price. On the other hand improved varieties are high yielding (Rezaul *et al*., 2011).

Starting from the past two decades many potato varieties has been improved and made available in east Africa. For example, Kenya Agricultural Research Institute (KARI) and National Agricultural Research Organization (NARO) in Uganda, in collaboration with International Potato Center (CIP) and Regional Potato and Sweet Potato improvement program for Eastern and Central Africa (PRAPACE) have released several improved potato varieties. Most of the released varieties have late blight resistance to help farmers in reducing losses from the disease (Kakuhenzire *et al*., 2004). However the adoptions of the improved vary between countries. For example, the area under improved varieties in Uganda is 69.3% of area under total potato production, while it is only 35.7% in Kenya. The findings closely reflect earlier observation indicating predominance of local varieties in Kenya, while the Uganda improved varieties were dominant, In addition to cultivars existed for many years in Ethiopia, research institutions, non-government organizations (NGO's) have also imported many more varieties, selected for specific traits, and distributed farmers to respond for the acute famine in Ethiopia. The mid 1980's drought resulted in the importation of more than 2,340 tons of potato seed of seven varieties from Europe; Cara, Spunta, Diamond, Cardinal, Barka, Ajax, and Alpha. Of these varieties, only Cara is reported still in production in some semi-arid and low land areas. The other has been completely eliminated by late blight (Gebremedhin *et al*., 2001).

The role that local farmers play in production and nurturing of diversity in enormous, the bulk of genetic diversity of agricultural crops in Ethiopia is still under farmers' holding, who continue to manage, improve and maintain this diversity in its dynamic state. These resources and farmers' effort to manage them are important to ensure the availability of the resources for use. Their value is not limited to their use within the country as shown by the contribution to world agriculture of early collections from Ethiopia by Harlan and Vavilov (Regga, 2006). One prior condition for high and stable yields is the choice of the most suitable potato varieties in compliance to the region's climate and soil particularities. Beyond the high yield potential, the chosen varieties must be resistance to main biotic and a biotic factor and must high quality potential (Imre-Otto, 2010).

High-quality seed is almost universally careful a requirement for good output in all potato production systems. A large amount of the yield gap at present constrain efficiency is attributed to the low quality of seed. Potato seed sector expansion is thus a main concern of governments, researchers, expansion agencies, and civil society organizations (Forbes *et al*., 2020). Seed is the most vital element of the production sequence of a lot of crops, including potatoes. Potato seed determines significant factors such as yield, quality and on the whole crop health. Starting with high-quality seed is the primary step to a successful crop time (Merk, 2019). Potato seed quality has a straight bearing on the potato productivity. Excellence of seed potato is vital for good yield therefore seed making; harvesting (hauling and harvesting) and storage should be cautiously approved out (Correa *et al*., 2007). The average give up add to from the use of high-quality seed is 30 to 50 percent compared to farmers' seeds (Sadawarti *et al*., 2020).

2.7. Effect of Planting Density on Tuber Production of Potato

Plant density affects the total yield as well as the average tuber size. By increasing plant density, yield increases, but the average tuber size decreases (Zebenay *et al*., 2019). Total yields increases to a maximum with increased stem density and then either remains unchanged with further increase in density or eventually begins to decline. Average tuber weight and tuber number are reported to be a significant components determining tuber yield (Elfinesh, 2008). According to (Geremew *et al*., 2010) explained that spacing has result on diverse variety as their root and leaf enlargement behavior. Optimizing of plant density is one of the significant aspects of potato production management because it affects seed cost, plant development, yield, and quality of the crop (Bussan *et al*., 2007). However, the optimum planting density for higher tuber yield of potato differs with the environmental situation of the production area, the soil fertility status, the variety used, and the purpose of production (Bikila, 2018).

Competition for nutrients in large plant density may associate with the make bigger in the number of tubers but with decreased tuber size or weight (Tesfaye *et al*., 2012). As the effect of rising the competition of plants for growth factors due to more number plant per unit area, which led to producing a high, number of undersize tubers which are high unmarketable tuber yield (Zebenay, 2015). However, in the wider inter row spacing improved exposure of plants for high radiation interception; hence increment the photosynthetic efficiency of the plant and 13 finally resulting in an increment number of tuber and tuber sizes per plant (Abera *et al*., 2017). In the same way (Tesfaye *et al.,* 2013) authors described that the more number of small-sized potato tuber was recorded at the closer inter row spacing, whereas the smallest number was obtained at the wider inter row spacing. This is due to the presence of more competition among plants for resources in the closer inter row spacing that leads to the production of lower medium-sized tubers.

According to (Alemayehu *et al.,* 2015) the most unmarketable tuber yields were produced from the highest planting density, whereas the lower unmarketable tuber yield was obtained at the lowest planting density. In the same way, at closer inter row spacing the competition of plants for growth factor is increased due to high number plant per unit area than wider inter row spacing which led to producing a high number of undersize tubers or high unmarketable tuber yield (Zebenay, 2015). Generally, many researchers described that potato planting at closer inter row spacing there is a high number of plant per unit area which brings about an increased ground cover and consequently influencing photosynthesis process but the number of tuber per plant and average tuber weight decreases due to more interplant competition.

2.8. Response of Potato Varieties on Inter Row Spacing

Potato variety difference in give up can be analyzed in terms of difference in increasing light assimilation. According to (Van Delden, 2001) determined that total biomass production and accumulation of potato varieties are dependent on the absorbed photo synthetically active radiation (PAR), which is in a straight line relative to the plant canopy cover. Leaf radiation absorption is governed by the speed of leaf appearance, leaf expansion, leaf size, geometry and guidelines. Potato varieties do be at variance in the production of leaves at little temperatures in such a method that horizontal leaves intercept lighter than erect leaves at low lAI, and the majority varieties vary significantly in this character. According to (Abong *et al.,* 2010) described the number of stems plant at maturity, stem and leaf dry weight at maturity and tuber dry weight compared to shoot dry weight was important due to variety and population. A significant difference has amongst variety in plant height, number of branches, leaf area, tuber number and tuber weight described that specific gravity, dry matter content differ considerably among the different potato variety. Potato crop development and tuber yields have been associated to the period of the enlargement cycle, which depends on climate, variety, and crop management.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted in Southern Nations, Nationalities, and Peoples` Regional State (SNNPRs), Hadiya zone Misrak Badewaccho district in Wera gera Keble Farmers Training Center (FTC), during the year 2022 G.C main cropping season. Misrak Badwacho district is one of the 13 districts of Hadiya zone. The district is bordered by Kambata Tambaro in north, Damot Gale district in south, west Badawcho district in west and Siraro Badawacho district in east. Geographically it is located at 7°.05' North and 37-38°.46' East.

According to the Misrak Badawacho Worada Metrological Station (unpublished) altitude range from 1580 to 2050 m.a.s.l, the mean annual temperature of the woreda is 20.1°C and the annual rain fall ranges between 800 mm to 1500 mm, and it is bimodal. The short rainy season extends from March to April and constitutes about 25% of the annual rainfall whereas the long rainy season extends from June to October and accounts for about 45% of the total rainfall, it characterized by fertile sandy loam and slightly acidic soil. The figure below shows the location map of the study area

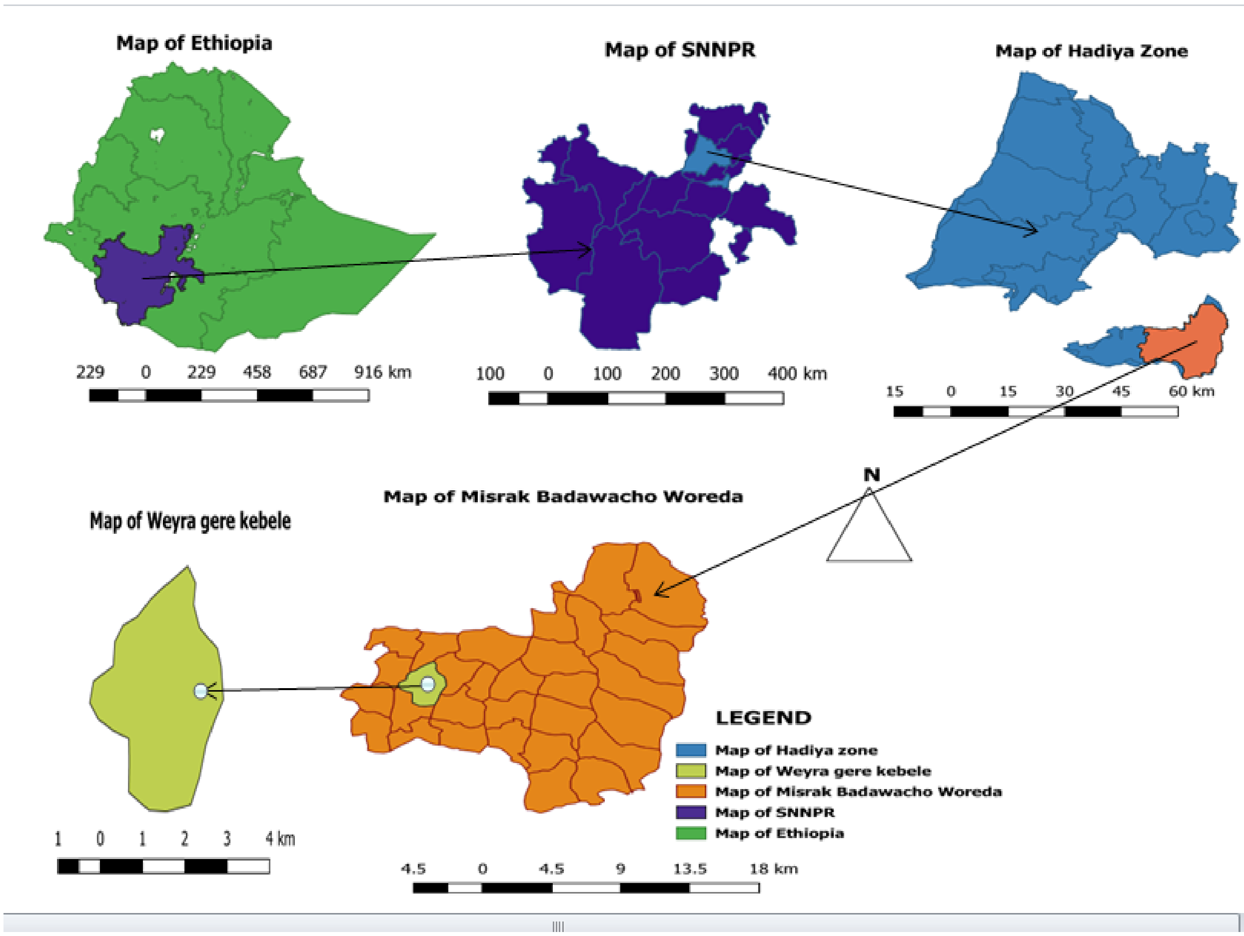

Figure 1: Map of the study area

3.2. Experimental Materials

For this experiment, four improved potato variety (Gudane, Zemen, Belete and Jalene) and one local variety was used (Table 1). The four potato varieties seed tuber used in the experiment was collected from Holetta Agricultural Research Center and one local variety was obtained from farmer who saved seed potato from previous season crops. Farmer's variety with semi erect growth habit which is preferred by farmers for its tuber characteristics, short dormancy period make it suitable for more than two cycles of potato production. The varieties were selected based on yield and diseases resistance characters and days to maturity indicated in table (Table1).

Table 1 : List of potato varieties that were used for the experiment

Variety	Year of released	Days to maturity	Altitudes	Yield (t/ha^{-1})	Purpose of release
Gudanie (CIP386423.58)	2006	120	1600-2800	29.2	Wide adaptable
Zemen (AL-105)	2001	76-101	1700-2000	37.2	East & West Hararge
Belete (CIP-393371.13)	2009	110	1600-2800	47.2	Wide adaptable
Jalenie (CIP-384321.19)	2002	100-110	1600-2800	44.8	Wide adaptable
Local	-	115-120	1600-3100		Not resistant to late blight

Source: - MoA, 1987-2020

3.3. Treatments and Experimental Design

Field experiment was conducted using the five potato variety and three inter row spacing. The three inter row spacing was 70 x 30 cm, 60 x 30 cm and 50 x 30 cm. With these two factors, the experiment was 5 x 3 factorial with a total 15 treatment combination arranged in a randomized complete block design (RCBD) with three replications in factorial arrangement. For 70 x 30cm, 60 x 30cm, 50 x 30cm, five rows consisting 40 plants, six rows consisting 48 plants, seven rows consisting 56 plants respectively, and for each plot one row containing 8 plants was used for each spacing treatments. The data were collected from the two middle rows lefting the plants at most end of each row as border plants.

Table 2 : Treatment of combination

Variety	Inter row Spacing	Combinations
Belete (CIP-393371.13)	70 x 30 cm	70 x 30 cm*B
	60 x 30 cm	60 x 30 cm*B
	50 x 30 cm	50 x 30 cm*B
Gudane (CIP386423.58)	70 x 30 cm	70 x 30 cm*G
	60 x 30 cm	60 x 30 cm*G
	50 x 30 cm	50 x 30 cm*G
Jalene (CIP-384321.19)	70 x 30 cm	70 x 30 cm*J
	60 x 30 cm	60 x 30 cm*J
	50 x 30 cm	50 x 30 cm*J
	70 x 30 cm	70 x 30 cm*Z
Zemen (AL-105)	60 x 30 cm	60 x 30 cm*Z
	50 x 30 cm	50 x 30 cm*Z
Local	70 x 30 cm	70 x 30 cm*L
	60 x 30 cm	60 x 30 cm*L
	50 x 30 cm	50 x 30 cm*L

Where, G = Gudane, Z = Zemen, B = Belete, J = Jalene, L = Local

3.4. Experimental Procedure

Land preparation

Land preparation was carried out in January 2022; the experimental field was cultivated to a depth of 25–30 cm using tractor. The land was divided in to block and plots. A distance of 1 and 1.5 m was maintained between plots and blocks/replications, respectively. Depending on proposed planting spacing's each plot was 8.4m^2. The land was leveled and a ridge was made according to the proposed planting spacing's by hand (Lung'aho *et al*., 2007).

Fertilizers application and other cultural practices

Fertilizers application: According to ATA (2006) recommendation, 150 kg urea and 200 kg NPSB (18.9% N, 37.7% P, 6.7% S and 0.1% B) ha^{-1} fertilizer was applied in band at sowing time. The whole NPSB fertilizer rate was applied during the time of planting; which was applied at the depth of 10 cm below the seed tuber at planting. Urea (46 % N) used as sources of Nitrogen and applied 7-10 cm away from the plant as two side dressings for subsequent split applications, where half nitrogen fertilizer was applied after full emerged (45 days after planting) and the remaining half of the nitrogen rate was applied at the initiation of tubers or start of flowering.

Other cultural practices: Weeding, cultivation and earthing-up were done at the appropriate time to facilitate root, stolon and tuber growth. Weeds was controlled by hoeing and earthing-up was done as required to prevent exposure of tubers to direct sunlight and for promoting tuber bulking and for ease of harvesting. A potato plant was treated at vegetative stage up to flowering time with Ridomil MZ 65 WP and Mancozeb 80% WP at the rate of 1.5 kg ha^{-1} diluted at the rate of 40 g per 20 liters water once a week to control late blight (Phytophthora infestans).

Harvesting: When the plants reached physiological maturity i.e when yellowing or senescence observed on the lower leaves, the haulm was mowed two weeks before harvesting to thicken tuber peri derm to avoid bruising and skinning during harvesting and post-harvest handling. Twenty plants from the two middle rows, left the plants growing in the two border rows as well as those growing at both ends of each row to avoid edge effects was harvested to estimate tuber yield and other yield-related parameters.

3.5. Data Collection and Measurements

Data was collected from five randomly selected plants from the middle rows of each plot. Data on phenological parameters, yield components and tuber quality which was taken from the two central rows as indicated above. The data recording and measurement for each parameter was carried out as follows:-

3.5.1. Phenological Parameters

Days to 50% emergency: This refers to the time required in days for the shoot to emerge from the tubers above the soil. It was recorded by counting the number of days from planting to until 50% of plants emerged in each plot.

Days to (50%) flowering: The numbers of days from planting to 50% flowering were recorded when 50% of the plants produce flowers in each plot.

Days to (90%) maturity: The number of days from planting to maturity were recorded when 90% of the plants in each plot become ready for harvest as indicated by the senescence of the haulms.

3.5.2. Growth Parameters

Plant height (cm): The height of the plants from the ground surface to the tip of the main stem was measured in centimeter at physiological maturity from the five randomly selected plants and was averaged to record the mean plant height in centimeter.

Stem number per hill: The total numbers of stems that arise from the ground was counted from the five randomly selected plants from each plot and was averaged to determine the mean number of stem number per hill. The actual number of stems per hill was recorded when 50% of the plants in each plot attained flowering stage.

Leaf number per plant: The total number of leafs that arise from the ground was counted from the five randomly selected plants from each plot and was averaged to determine the mean number of leafs number per hill. The actual number of leafs per hill was recorded when 50% of the plants in each plot attained vegetative stage.

Leaf area (cm^2): Leaf area was measured by leaf length (cm) x leaf width (cm). leaf were from the middle part of the plant by selecting five plant leaves at random from each plot and then the average was done at full maturity stage from five sampled plants.

Leaf area index: To determine leaf area index, five plants (hills) from each plot were randomly sampled and tagged. Individual leaf area of the potato plants were estimated from individual leaf length using the following formula developed by Firman and Allen, (1989) and leaf area index was determined by dividing the total leaf area of a plant by the ground area covered by the plant according to the following formula:

Log10 (leaf area in cm2) = 2.06xlog10 (leaf length in cm) - 0.458

Harvest index (%): refers to the ratio of tuber dry matter to the total dry matter at harvest. It was determined from underground dry biomass and total dry biomass which was measured as indicated in each parameter. Then, harvest index were computed by dividing the underground dry biomass by the total dry biomass per plant and multiplied by 100.

3.5.3. Yield and Yield Components Parameters

Total dry biomass yield (kg): This refers to the total dry weight of leaves, stems, roots, stolons, and tubers at physiological maturity. To determine the dry weight five randomly selected plants were harvested from each plot when the vines were still green but practically cease growth. The five randomly selected plants from each plot were taken and the average weighed was calculated to record dry biomass yield per plant.

Total tuber yield (ton ha^{-1}): This refers to the entire tubers harvested from selected plants and converted in to hectare. It was recorded by adding up the weights of marketable and unmarketable tubers.

Marketable tuber yield (ton ha^{-1}): This refers to the tubers which were free from blemishes due to diseases, insect pests, physiological disorders, and that weighs greater than or equals to 20 g. Each planting spacing and by calculating total population per hectare for each (first were determined per plot and then converted to ton ha^{-1}.

Unmarketable tuber yield (ton ha^{-1}): This refers to tubers that were had blemishes due to attack by pests, infection by diseases, deformed due to physiological disorder and that weigh less than 20 g. It was first determined per plot and then converted to ton ha^{-1} for each treatment at harvest.

Tuber number per hill: This was obtained by counting the actual number of tubers harvested at maturity and dividing the number of tubers by the total number of plants harvested.

Tuber size distribution (g): This refers to the yield of proportional weight of tubers in size categories. All tubers from five randomly taken plants per plot were categorized into small (< 39 g); medium (39-75 g) and large (>75 g) according to Lung'aho *et al.* (2007). The proportion of the weight of each tuber category were expressed in percentage and the average of each category were recorded a single plant.

Marketable tuber number per hill: Tubers from the five randomly selected plants per plot which are tuber size greater than 20g were measured and counted and converted in to hectare at the harvesting stage.

Unmarketable tuber number per hill: randomly selected five plant tubers per plot which are under-sized tubers (<20g) as well as diseased, cracked and rotten were measured and counted and converted in to t/ha^{-1}.

3.5.4 Tuber Quality Parameters

Tuber dry matter content (%): from the five randomly selected plants from each plots, 200g fresh tuber was randomly taken, washed and fresh weigh was taken and then sliced. It was dried for seven days under sun and further dried in an oven at 75^{o}C for 72 hours until a constant weight was obtained and dry matter percent were calculated according to William and Woodbury, (1968).

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

Specific gravity of tubers: This was determined by the weight in air and weight in water method. Five kg tubers of all shapes and sizes were randomly taken from each plot. The selected tubers were washed with water. The sample was first weighed in air and then re-weighed suspended in water. Specific gravity was calculated using the following formula, developed by Kleinkopf *et al*, (1987).

$$\text{Specific gravity} : \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in Water}}$$

Total starch content (g): The percentages of starch were calculated from the specific gravity where specific gravity was determined as indicated above by the weight in air and weight in water method.

Starch (%) =17.546 + 199.07 × (specific gravity-1.0988) (Smith and Talburt 1959).

3.6. Data Analysis

Data was analysed by variance of the GLM procedure of factorial Randomized Complete Block Design (RCBD) using SAS Version 9.2 and the data was checked for meeting the various ANOVA assumptions. Finally the results were compared by using LSD value at 5% different significance level.

4. RESULTS AND DISCUSSIONS

4.1. Effect of variety and inter row spacing on days to 50% emergency; 50% flowering and 90% maturity

4.1.1. Days to 50% emergency

Analysis of variance showed that the main effect of variety significantly ($P < 0.05$) affected days to 50% emergency, where as the inter row spacing and interaction had no significant effect (Table 3 and Appendix 1). Local variety took longest (18.66) days to 50% emergency while variety Zemen had taken shorter (13.33) days to 50% emergency. These variations in days to 50% emergency may be governed by genetic factors, they location where the variety were grown-up and ability to store food reserves in their seed potato. Different varieties had different ability to store food and provide an optimal supply of carbohydrate for the emerging seedling of embryo. This result is harmony with the findings of Abubaker *et al*. (2011) who reported that the genetic difference could be attributed to days to emergency difference among of potato variety and ability to store food.

Similarly, (Addisu *et al*., 2013) confirmed highly significant differences with respect to days to emergence among different potato varieties. The authors explained that it could be owing to the genetic makeup of the variety coupled with the differences in the handling of seed tubers. Conversely, plant density did not affect days to 50% emergence showing the consumption of reserve material and metabolites in the mother potato tuber (Masarirambi *et al*., 2012) also suggested that density had no significant influence on days to emergence of potato tubers.

4.1.2. Days to 50% flowering

The result indicates that the main effects of inter row spacing and variety and their interaction showed significant ($P < 0.05$) difference on days to 50% flowering of potato (Figure 2 and

Appendix 1).The longest days to 50% flowering (61.16) was scored from plots of local variety planted at an inter row spacing of 70 x 30 cm. While the shortest day (47.66) was scored from Zemen variety planted at an inter row spacing of 50 x 30 cm (Figure 2). The result showed that local variety had taken was longer days when planted at all inter row spacing tested. These could explain by the difference in their genetic makeup of this variety and environmental adaptability among tested varieties to the differences in wider inter row spacing took longest days to 50% flowering due to the exposure to get ample light and nutrient that could hold back the transition of vegetative phase to the reproductive time than those planted in a closer inter row spacing. Plants in a closer inter row spacing shortest days to flowering may compete for the accessible light and nutrients this might elicit signal to transact hastily to reproductive phase than plants in a wider inter row spacing that does not compute for light and nutrients. This result in agrees with the findings of (Sadik *et al*., 2018) who reported that closer inter row spacing could decrease vegetative growth and enhance flower formation on potato plant and wider inter row spacing increase days to 50% flowering because no competition for light and nutrients. Similarly, demonstrated that increasing inters and intra-row spacing effect in delaying the time needed reaching 50% flowering in potato.

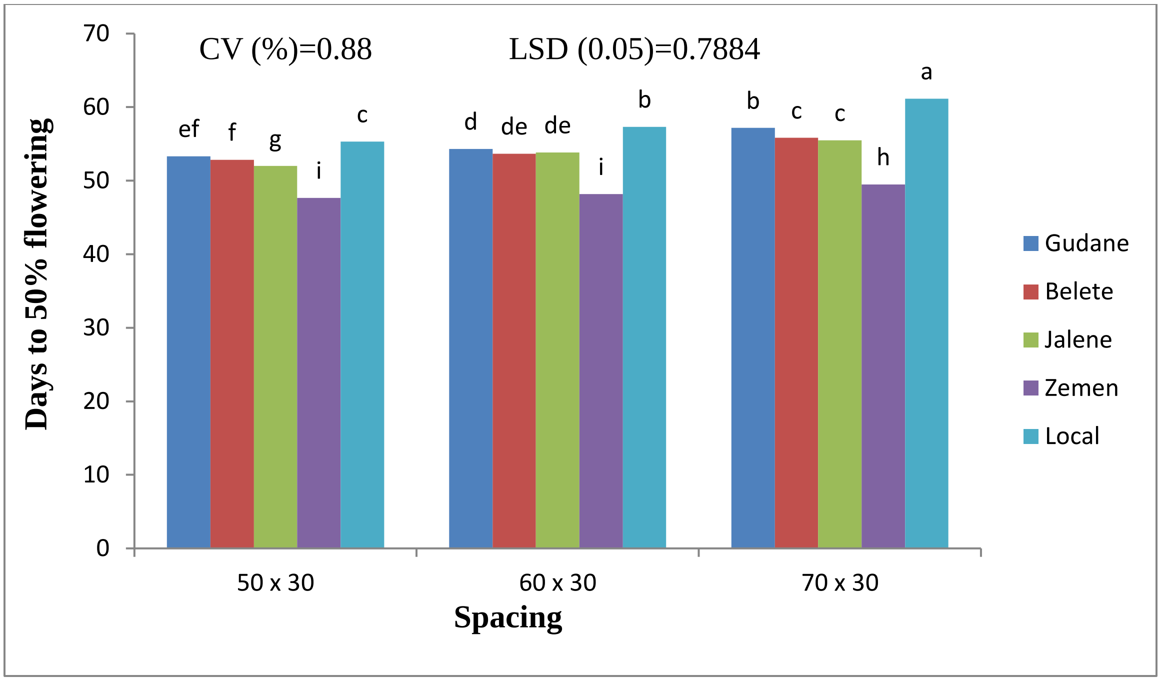

Figure 2: Interactions effect of inter row spacing and variety on days to 50% flowering in potato

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.1.3. Days to 90% maturity

The main effect of variety and inter-row spacing significantly ($P < 0.05$) affected the days to 90% maturity of potato but interaction had not (Table 3 and Appendix 1).The highest (113.67) days to 90% maturity of potato was recorded from local variety while the lowest (87.00) days to 90% maturity of potato was recorded from Zemen variety (Table 3). These may explain that it take for maturity a factors of the variety planted time, the plant density and climatic conditions. This is on harmony with the report of Musa *et al*. (2007) who well-known that the maturity is a varietal attribute which of course can be challenged by planting date, climatic condition and adopted farming practices. Conversely the shortest days (98.47) to maturity was scored at closer inter row spacing (50 x 30 cm) whereas longest days (104.73) to maturity were scored from wider inter row spacing (70 x 30 cm). Increasing inter row spacing delayed the time required to arrive at maturity.

Hasty maturity in answer to closer inter row spacing is an indicator of competition for growth factors while at wider inter row spacing the competition is fewer which favor enlargement and longest days to maturity. The present results agree with the finding of (Birhanu *et al.,* 2016) who reported that closer inter row spacing had reduced days to maturity. In the same way (Harnet, 2011) reported that wider inter row spacing not only belated maturity but in addition caused whole yield decrease in large area of land. The result might show the significant mutual result of inherent characteristics of variety and plant density on the plant physiological maturity. The observed hastened maturity of variety across the different seed tuber in reply to high- plant density could be attributed to stiffer competition among plants for growth factors. Under stiffer competition for growth factors, plants tended to mature earlier in the season, which mainly coincided with the early tuber initiation to complete their life cycle and vice versa. Other researchers also reported significant differences in days to 90% physiological maturity among potato variety (Helen, 2012).

Table 3: Effect of variety and inter row spacing on days to 50 % emergence and 90 % maturity in potato

Treatment	Days to 50 % emergence	Days to 90 % maturity
Variety		
Gudene	15.611^{b}	104.56^{b}
Belete	15.000^{c}	99.78^{d}
Jalene	14.556^{d}	102.89^{c}
Zemen	13.333^{e}	87.00^{e}
Local	18.6667^{a}	113.67^{a}
LSD(0.05)	0.3108	1.0294
Spacing (cm)		
50 * 30		98.47^{c}
60 * 30		101.53^{b}
70 * 30		104.73^{a}
LSD (0.05)		0.7974
CV %	2.09	1.05

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.2. Effect of inter row spacing and variety on stem number per hill, plant height and leaf number per plant

4.2.1. Stem number per hill

The stem number per hill was significantly ($P < 0.05$) affected by main effect of variety whereas inter row spacing and its interaction not significant difference (Table 4 and Appendix 2).The highest (6.28) and the least (3.34) stem number per hill was obtained from Gudene and local varieties, respectively (Table 4). This difference could be because of the inherent variations in the number of buds per tuber of potato varieties which are possibly genetically determined. The difference in the number of stem amongst the varieties evaluated may be because of the natural inherent difference in the numeral of buds per tuber which is challenged by the size of the tubers, physiological age of the seed and number of feasible sprouts at planting. The consequence is reliable that the findings of Habtamu *et al.* (2016) author described to the quantity of stems per hill are challenged by variety and genetic makeup. The variety of potato tuber is typically propagated by means of underground storage organs known as tubers. Potato tubers show a broad range of difference and possess an uneven number of mounting points (buds) approved in groups (eyes) over their surface. This buds set in groups are accountable for variation in sprouts leading to differences in the stem numbers per hill. The consequence in harmony with the findings of (Abebe *et al*., 2010) reported that the stem number could vary depending on the storage situation, physiological period of the seed of the variety and tuber size. These could be as a result of the actuality that privileged rivalry for sunlight, nutrient and gap amongst vegetation developed at the closure inter row spacing to the plant for the period of its active growth phase, improved the development and increase of extra quantity of stem. The number of stems per hill had straight relative with the number of sprouts per tuber not on the treatment applied and the sprouts are the function of number of eyes on tubers. According to (Harnet, 2011; Frezgi, 2007) who reported that the number of stems per hill was not subjective by plant density rather it is influenced by variety. also described that plant distance settle on the number of shoots per section of area and every stem behave as difference potato plant as every have its own root and stem organization.

4.2.2. Plant height (cm)

Analyses of variances showed that plant height was significantly ($P< 0.05$) influenced by the main effects of inter row spacing and variety but their interaction was not significant (Table 4 and Appendix 2). The longest plant height (83.94 cm) was recorded from variety Gudene and the shortest (45.77 cm) was from local variety. This variation in plant height among the tested potato variety might be because of hereditary compositions, soil nutrients and growing environments. This result agrees with the findings of El-Tohamy *et al.* (2006) who reported the highest plant height at wider inter row spacing could be because of better accessibility of soil nutrients, particularly Nitrogen and Phosphorus which resulting in vegetative enlargement of plants by enhancing cell division and elongation. Also another authors reported that Berhanu and Tewodros (2016) and Zerihun (2016) who establish an important result of environment, variety and their interaction on plant height. In contrast, the shortest plant height (66.20) was scored at closer inter row spacing (50 x 30 cm) whereas highest plant height (77.66) was scored from wider inter row spacing (70 x 30 cm). This is could be as a result of that plants at wider inter row spacing experienced less competition for growth resources such as water, light and nutrients and grow more vegetative whereas, closer inter row spacing that show strong competition for nutrients then reduced the plant height. This higher numbers of stem numbers with advanced leaf numbers, LAI and on the whole higher canopy that favors a higher photosynthetic rate will have an advanced enlargement tempo and plant height. These result agree with the finding of (Bekele, 2018; Wolde Mariam, 2009) were revealed that difference among plant height was observed for variety. At wider inter row spacing the longest plant height was measured and at narrower inter row spacing shortest plant height was identified.

4.2.3. Leaf number per plant

The results of the present study showed that the main effects of inter row spacing and variety was showed significant ($P < 0.05$) difference on leaf number per plant whereas its interaction not significant (Table 4 and Appendix 2). The maximum (223.56) leaf number per plant Gudene and minimum (135.33) from local variety was scored. In contrast, the largest (213) potato leaf numbers per plant was revealed at the wider inter row spacing of 70 x 30 cm whereas, the lowest (186) potato leaf numbers per plant was scored at the narrower inter row spacing of 50 x 30 cm. At the wider inter row spacing due to the presence of the low amount of competitions between plant, plants absorbed the sufficiently available resources and lighter and increased their photosynthetic efficiency that further incremented the vegetative growth and ultimately resulted in increased leaf number per plant also accepted that leaf number decreased in the narrower inter row spacing because high amount of competitions between plant. This result harmony with the findings of (Yenegi *et al.*, 2004; Oliveira, 2000) reported that narrower inter row spacing decrease in leaf numbers per plant due to high plant density could be as a result of increasing number of plant a piece of land exerts competition among plants for nutrients and light that cause a decrease in leaf numbers per plant compare to wider inter row spacing. Similarly, (Mvumi *et al.*, 2018; Mangani *et al*., 2015) authors found that there be maximum number of leafs at low number of plant density proportional to the high number of plant density.

Table 4: Effect of variety and inter row spacing on stem number per hill, plant height and leaf number per plant in potato

Treatment	Plant height (cm)	Leaf number per plant	Stem number per hill
Variety			
Gudene	83.944[a]	223.567[a]	6.2889[a]
Belete	81.111[b]	219.222[a]	5.6000[b]
Jalene	75.222[c]	217.444[a]	4.8556[c]
Zemen	75.833[c]	202.000[b]	4.3556[c]
Local	45.775[d]	135.333[c]	3.344[d]
LSD (0.05)	1.1848	6.2130	0.6416
Spacing (cm)			
50 * 30	66.200[c]	186[c]	
60 * 30	72.733[b]	198[b]	
70 * 30	77.666[a]	213[a]	
LSD (0.05)	0.9178	4.8126	
CV %	1.70	3.22	13.59

Note: means with similar letters (s) in a column are not significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.3. The main effect of inter row spacing and variety on leaf area; leaf area index and harvest index

4.3.1. Leaf area (cm^2)

Interaction effect of variety and inter row spacing was showed significant ($P< 0.05$) difference on leaf area of potato (Figure 3 and Appendix 2). The highest leaf area (53.7 cm^2) was obtained from at interaction of inter row spacing (70 x 30 cm) and Gudene variety whereas the lowest leaf area (22.5 cm^2) were recorded from at interaction of inter row spacing (50 x 30 cm) and local variety. The highest (49.33 cm^2) leaf area was scored at interaction of inter row spacing (60 x 30 cm) and Gudene variety. The results showed that were obtained statistically similar results from at interaction of inter row spacing (70 x 30 cm) and Zemen and Belete variety. These difference leaf areas among the tested potato variety could be because of difference in the hereditary compositions of varieties. Similar result has been presented by (Yenagi *et al.,* 2004; Oliveira, 2000) who have reported that the leaf area of potato tubers affected by potato hereditary makeup and variety. In this study, the result indicated that increasing inter row spacing might be the result in increment of potato leaf area and reducing inter row spacing with decreasing leaf area of potato. The result in harmony with the finding of Tsegaye (2014) who reported as plant density increases plant leaf area would be reduced. Similar results were also reported other studies where leaf area and plant population had negative relationship (Yenagi *et al.*, 2004; Oliveira, 2000). On the other hand when planted at wider inter row spacing plants absorb the adequately resources (nutrient, lighter) and which enhances their photosynthetic effectiveness and vegetative enlargement that eventually effected in larger leaf area per plant.

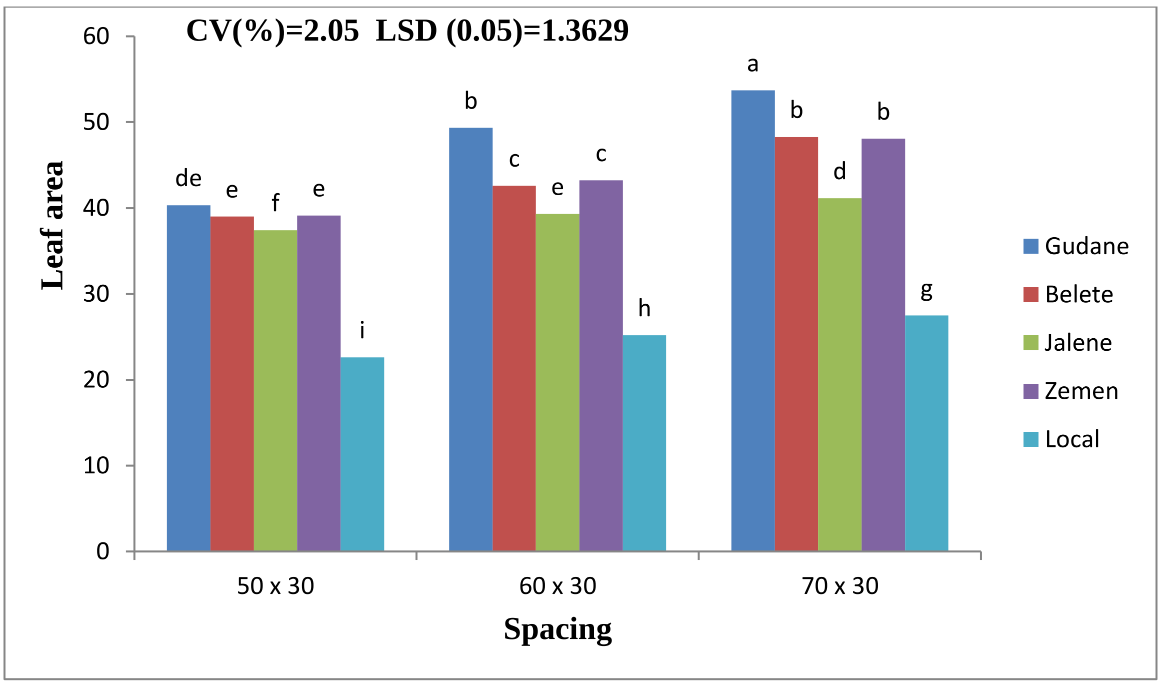

Figure 3: Interactions effect of inter row spacing and variety on leaf area in potato

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.3.2. Leaf area index`

Leaf area index (LAI) was highly (P< 0.05) influenced by both the main effect of variety and inters row spacing. But the interactions effect was not showed significant difference (Table 5 and Appendix 2). The highest (3.66) leaf area index Gudene and lowest (2.22) local variety was recorded. This might be indicating that the environmental growing condition and varieties for leaf area index. This result is in harmony with the findings of Puts (1986) who described existence of important difference among variety in the leaf area index and growing locations. The highest (3.44) leaf area index was scored at inter row spacing of 50 x 30 cm and the lowest (2.67) leaf area index was scored at inter row spacing of 70 x 30 cm. Within inter row spacing 50 and 60 cm leaf area index was not showed significance difference but increases in LAI with the decreasing inter row spacing from 70 to 50 cm there is significance difference. This indicate that the closer inter row spacing effect in a good canopy coverage for more photo-assimilation to take place through light interception, and might be effect in good tuber yields of the variety than the wider inter row spacing leaf area index. The result is agrees to the findings of Birhanu (2014) and Tesfa (2012) described that increasing in leaf area index of potato inter row spacing was closured. It most likely could be attributed to the increase in leaf area coverage of the soil surface until ample light became trapped for optimally improved productions of photo assimilate. High LAI usually indicate that the crop can intercept extra solar radiation for photosynthetic activity. Similarly, (Ronald, 2005) who revealed so as to the highest density increased leaf area index, probably indicating potential partitioning of assimilates for vegetative growth and LAI in potato increased with decreased inter row spacing.

4.3.3. Harvest index

The results revealed that highly ($P < 0.05$) significant in response to the main effects of inter row spacing and variety whereas its interaction was not showed significant (Table 5 and Appendix 2). The highest (0.76) harvest index Gudene and the least (0.46) harvest index local variety were recorded. The variations observed in harvest index of potato variety might be attributed to their inherent genetic differences as well as the varieties and plant density, which were manifest from the important relations. The result harmony with the findings of Helen (2012) stated that the variations observed between the varieties in harvest index might be attributed to their genetic differences and plant populations. Conversely, closer inter row spacing of 50 x 30 cm outcome largest (0.71) harvest index and the smallest (0.556) harvest index scored inter row spacing at 70 x 30 cm. That means the most of the time its effectiveness associated with inter row spacing and the environments there was reduced tendency in harvest index in response to reducing planting density. In agreement with the finding of (Helen, 2012) stated that the variations observed between the variety in harvest index might be attributed to their plant density, growing situations and indicated that in temperate zones, harvest indices of 0.75-0.85 (75-85%) are quite common, but in warmer climates, the harvest index tends to be lower than the temperate zone and often a wider variation is also observed between variety or growing conditions.

Table 5: Effect of variety and inter row spacing on leaf area and harvest index in potato

Treatment	Leaf area index	Harvest index (%)
Variety		
Gudene	3.660[a]	0.758[a]
Belete	3.492[b]	0.747[a]
Jalene	3.084[c]	0.606[b]
Zemen	2.735[d]	0.600[b]
Local	2.223[e]	0.462[c]
LSD(0.05)	0.1294	0.0260
Spacing (cm)		
50 * 30	3.448[a]	0.715[a]
60 * 30	2.999[b]	0.633[b]
70 * 30	2.670[c]	0.556[c]
LSD (0.05)	0.1002	0.0201
CV %	4.39	4.24

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.4. Effect of inter row spacing and variety on total dry biomass and total tuber yield

4.4.1. Total dry biomass

The main effects revealed that inter row spacing and varieties were showed significant (P < 0.05) difference on the total dry biomass however did not the interaction significant (Table 6 and Appendix 3). The highest (292.03 g) total dry biomass obtained from Gudene and the lowest (198.85g) local variety were recorded. The variations of potato varieties in all total dry biomass yields are linked with the difference in the hereditary composition of the potato varieties. This result agreement with the findings of Lemma *et al*. (2020) the authors described that those variations of genetic compositions in potato varieties had significance difference with regard to tuber and tuber associated character. Alternatively, the highest (276.67 g) total dry biomass yield findings from (70 x 30 cm) and the smallest (226.52 g) inter row spacing (50 x 30 cm). The biomass yields were increased as increasing inter row spacing was attributed to the minimum competition among the plants for nutritious. The lowest total dry biomass yield could be attributed to the low number of stems and leaves, short plant height and low leaf area index of the local variety as relatively to the improved variety as observed in the experiment. This result agrees with the findings of (Getachew *et al*., 2013; Gebremedhin *et al*. 2001) described that, biomass yield increment in respond to competition among the plants nutritious indicates that could exert a significant influence on biomass production and partitioning to the different parts of potato plants. According to (Morena *et al*., 1994) also indicated that plants from old seed tubers displayed reduced shoot, root, and leaf dry weights; these effects reflect altered dry matter partitioning and contributed to all over change in plant morphology with advanced tuber.

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

The result indicates that the main effects of inter row spacing and variety was significant (P< 0.05) difference on total tuber yield of potato however, its interaction did not show significant difference (Table 6 and Appendix 3). The highest tuber yield (35.6t/ha^{-1}) per hectare was recorded from Gudene and followed by Belete variety (34.16t/ha^{-1}) and lower whole tuber per hectare was recorded from local variety (22.50t/ha^{-1}). The difference in total tuber yield between potato varieties has been reported by many authors (Abebe *et al*., 2021; Lemma *et al*., 2020 and Habtamu *et al.,* 2016). They reported that such difference could be because the tuber and tuber associated character, genotype and environment. Similarly, (Lemma *et al*., 2020) who reported that experimental significant difference with high opinion to tuber yield owing to genotype and environment. The effect regarding inter row spacing showed that narrower inter row spacing increases whole tuber yield of potato significantly higher (32.16 t/ha^{-1}) whole tuber yield scored from closer inter row spacing (50 x 30 cm) on the other hand at the wider inter row spacing (70 x 30 cm) revealed that the lower (28.00 t/ha^{-1}) total tuber yield were scored. In additional words, narrow inter row spacing increasing plant density that could be increasing total tuber yield per section area of land. It probably could be attributed to the increase in leaf area coverage of the soil surface until sufficient light became trapped for optimally increased productions of photo assimilate. This result in harmony with the studied of (Zebenay, 2015; Harnet, 2011) authors reported plant density powerfully affected yield, both by number and weight, and extra tubers numbers and give up per square meter were predictable in higher plant densities.

Table 6: Effect of variety and inter row spacing on tuber yield per ha^{-1} and total dry biomass in potato

Treatment	Total tuber yield per ha^{-1}	Total dry biomass
Variety		
Gudene	35.66[a]	292.03[a]
Belete	34.167[b]	281.61[b]
Jalene	30.056[c]	257.79[c]
Zemen	29.944[c]	235.73[d]
Local	22.500[d]	198.85[e]
LSD (0.05)	1.1430	7.6725
Spacing (cm)		
50 * 30	32.167[a]	226.52[c]
60 * 30	30.333[b]	256.42[b]
70 * 30	28.000[c]	276.67[a]
LSD (0.05)	0.8854	5.9431
CV %	3.89	3.14

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.5. Interaction effect of variety and inter row spacing on marketable and unmarketable tuber yield

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

The analyses of variance indicated that the main effects of inter row spacing and variety and their interaction was showed significantly ($P< 0.05$) affected marketable potato tuber yield t/ha^{-1} (Figure 4 and Appendix 3).The highest (36.00 t/$ha-^{1}$) marketable potato tuber yield was obtained from Gudene variety planted at inter row spacing (60 x 30 cm) whereas lowest (12.83 t/$ha-^{1}$) marketable potato tuber yield was recorded from local variety planted at inter row spacing (50 x 30 cm). Variety Gudene produced two fold more yield over local variety when it planted at inter row spacing of 60 x 30 cm. Increasing inter row spacing with increased marketable tuber yield of all potato varieties tested in this experiment. This might be due to the presence of less competition for resources, where the plants can absorb sufficient available resources (nutrient, light, moisture). This increased their photosynthetic efficiency for higher photo assimilate production and ultimately resulted in increased more marketable tuber yield. Also it might be due to both genetic and environmental factors that play a crucial role in stolon development and tuberization process. The probable cause for the increment yield per hectare might have been due to having the higher number of the tubers so used the seedling to set up which leads optimum density mass per hectare and, these contributes the capability to produce tuber yield. The result harmony with the findings of Tesfa (2012) reported that an optimum number of inter rows spacing per section of area increase marketable yield per hectare and extra inter row spacing also reduced marketable yield per hectare of potato. Also (Kumar *et al*., 2007) who examine that marketable potato yield was significantly various by variety, place and genotypes x surroundings interaction.

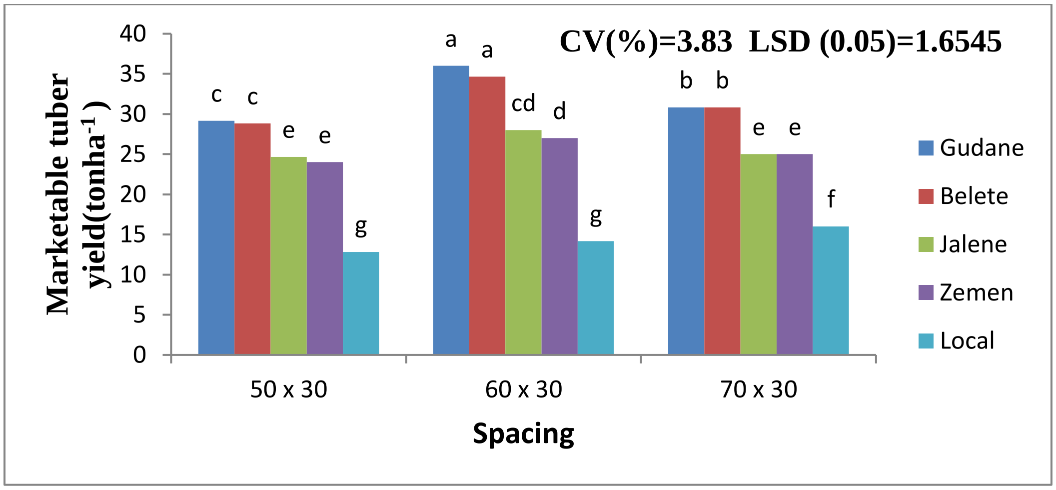

Figure 4: Interactions effect of inter row spacing and variety on marketable tuber yield per hectare in potato

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

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

Interactive effect of variety and inter row spacing significantly ($P < 0.05$) affected unmarketable tuber yield of potato (Figure 5 and Appendix 3). The highest (10.66 t/ha^{-1}) unmarketable potato tuber yield was scored from local variety and planted at inter row spacing of 50 x 30 cm. The lowest (2.0 t/ha^{-1}) unmarketable potato tuber yield was scored from Belete variety and planted at inter row spacing of 70 x 30 cm. The highest (7.83 t/ha^{-1}) unmarketable potato tuber yield was scored from local variety and at interaction of inter row spacing (60 x 30 cm). The results showed that local variety produced unmarketable potato tuber yield three fold more over Belete variety planted at inter row spacing of 50 x 30 cm. The difference in unmarketable potato tuber yield could be due to adaptability, crop maturity, and natural capability of potato genotypes in producing unmarketable potatoes. According to (Bekele, 2018; Haile *et al*., 2015) showed that difference among genotypes of unmarketable yield could be attributed to their genetic make-up and plant density. Potato closer inter row spacing give up highest unmarketable tuber yield due to closer inter row spacing there is stiff inter-plant competition for growth factors, which result in the production of more numbers of undersized tubers. While at wider inter row spacing unmarketable potato yield become reduced because there is no intensive competitions for growth factors. The result agrees with the findings of (Zebenay, 2015) who report that narrower inter row spacing amplified competition of plants for growth factors due to large number plant per section area than wider inter row spacing which lead to generate large number of beneath size tubers which was high unmarketable yield.

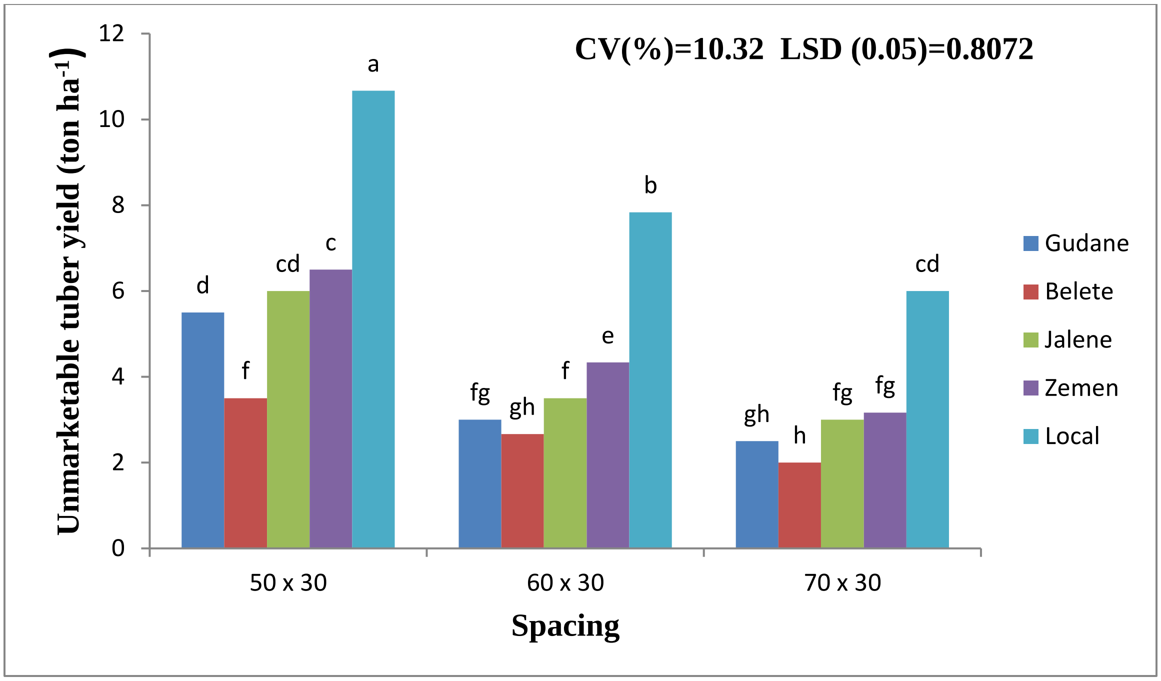

Figure 5: Interactions effect of inter row spacing and variety on unmarketable tuber yield per

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.6. Effect of variety and inter row spacing on tuber number per hill and tuber size distribution

4.6.1. Tuber number per hill

Both the main effect of variety and inter row spacing had significant difference ($P < 0.05$) of potato tuber number per hill but interaction had no effect (Table 7 and Appendix 3). The highest (13.28) average tuber number per hill Gudene and least (7.20) local varieties was scored. The difference may be attributed to that the difference in hereditary prospective among potato variety. Stolen and tuberization process is influenced by inherent makeup and ecological factors (Bekele, 2018). These results are in harmony with the findings of Lamessa and Zewdu (2016) who described that the average tubers number per hill were different in hereditary factors. The highest (12.56) tuber number per hill was obtain at wider inter row spacing tested (70 x 30 cm) and the least (9.28) was from narrower inter row spacing tested (50 x 30 cm). At lower plant density, competition is fewer, which consequences in a larger number of tubers per hill, but in addition in a lower number of tubers per section area. Conversely when plant density increased, the number of tubers per hill reduced, but the numbers of tubers per unit area normally increase. This in all probability due to the number of tubers produced depends on the competition among the plant for enlargement factors such as nutrients, water and light. The outcome of the study is in line up with result of Zebenay (2015) who elucidate that the maximum numbers of tuber produced at narrow inter row spacing than at wider inter row spacing which leads to the production of largest number of whole tubers per hill.

4.6.2. Small sized tuber (%)

Small size tuber was significantly ($P < 0.05$) affected by the main effect of variety and inter row spacing whereas interaction did not have significant an effect (Table 7 and Appendix 4). The largest (40.50%) proportion of small sized tubers obtained from local and the smallest (11.68%) was from Belete variety. This consequence are in agrees with the findings of (Bilate and Mululalem, 2016; Helen, 2012) reported that plants from imported seed produced a higher percentage of large and medium size tubers than plants from local seed tubers, which produced a higher percentage of small size tubers and also reported that the plants from the certified seed produced a higher percentage of large and medium size tubers than the local seed tubers, which produced small tuber size. Conversely at narrow inter row spacing proportion of highest small size tubers (29.12%) be get hold of from (50 x 30 cm) there would be high competition between plants for nutrient and growth challenge which guide to produce maximum give up of low seed tuber sizes while the smallest small sized tubers (19.64%) were scored from (70 x 30 cm) there would be low competition between plants for nutrient and growth factor which guide to produce minimum yield of low seed tuber sizes. This result is harmony with the findings of (Tesfaye *et al*., 2013) who reported that the statistics of small-sized tuber making incremented at the narrow inter row spacing and the plant population increased the yield and number of small seed tuber sizes also increased.

4.6.3. Medium sized tuber (%)

The result indicated that medium tuber sized had significantly ($P < 0.05$) influenced by the main effects of inter row spacing and variety however its interaction not significant effect (Table 7 and Appendix 4). The largest (77.36%) proportion of medium sized tuber from Belete and the smallest (58.49%) local varieties were scored.   These outcome is in harmony with the findings of Bilate and Mululalem (2016) and Habtamu *et al*. (2016) who pragmatic highly significant difference amongst potato variety with look upon to proportion of medium sized potato tuber. Conversely, the largest (72.59%) medium-sized tuber yield was revealed at a wider inter row spacing of (70 x 30 cm) and the smallest (67.64%) obtained at closer inter row spacing (50 x 30 cm). The effect indicated that with reduced inter row spacing the yield of medium-sized tuber was increased. This might be at wider inter row spacing had no competition between plants for nutrients and other enlargement challenges which guide to produce maximum give up of medium seed tuber sizes. These outcomes is in harmony with the findings of (Tesfaye *et al*., 2013) who reported that the largest number of medium-sized tuber was obtained from wider inter row spacing than closer inter row spacing, due to low competition amongst plants for nutrients.

4.6.4. Large sized tuber (%)

The result showed that large sized tuber was significant differences of ($P < 0.05$) the main effect of variety and inter row spacing but not their interactions (Table 7 and Appendix 4). The highest

(10.94%) proportion of big sized tuber Belete and the smallest (1.04%) local variety was recorded. This difference realistic for proportion of big sized tuber would be hereditary prohibited and the observed significant difference amongst the variety for tuber size allocation may be attributed to genotypes potential of the variety. These result is harmony to the finding of (Habtamu *et al.*, 2016) who agrees that significantly peak number of big size tubers in quantity was intended for Belete variety developed in eastern Ethiopia and Bilate and Mululalem (2016) in addition described that big sized tuber number per hill was considerably affected by variety, this effect could be big seed tuber size had high food reserves than undersized and intermediate seed tuber sizes. More big-sized tuber yield are revealed from big seed tuber size, since it has maximum content of carbohydrate to feed plant growth. However, undersized seed tubers had no capability of equivalent rivalry with other plants for assets and had also a small quantity of carbohydrates basis to hold up plant at earlier development phase. The largest yield of big-size tuber (7.70%) be scored from wider inter row spacing (70 x 30 cm) and the smallest (3.33%) was obtained at closer inter row spacing (50 x 30 cm) this consequence could be at wider inter row spacing had a small competition between plants for nutrients and development factors than narrow inter row spacing, which guide to makes largest yield of big-sized tubers. This outcome is in agrees with the findings of (Tesfaye *et al*., 2013) who mention that the maximum number of big-size tubers was scored at wider inter row spacing as relative to closer inter row spacing.

Table 7: Effect of variety and inter row spacing on tuber number per hill and tuber size distribution in potato

Treatment	Small size (%)	Medium size (%)	Large size (%)	Tuber number per hill
Variety				
Belete	11.686[e]	77.369[a]	10.945[a]	13.289[a]
Gudene	14.081[d]	76.786[a]	9.133[b]	11.967[b]
Jalene	25.494[c]	70.258[b]	4.248[c]	11.178[c]
Zemen	29.129[b]	67.742[c]	3.129[d]	10.856[d]
Local	40.506[a]	58.490[d]	1.004[e]	7.200[e]
LSD (0.05)	0.4720	0.8104	0.1969	0.2759
Spacing (cm)				
50 * 30	29.024[a]	67.641[c]	3.335[c]	9.287[c]
60 * 30	23.869[b]	70.625[b]	5.506[b]	10.847[b]
70 * 30	19.644[c]	72.596[a]	7.760[a]	12.560[a]
LSD (0.05)	0.3656	0.6277	0.1525	0.2137
CV %	2.02	1.19	3.58	2.62

Note: means with similar letters (s) in a column are not significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.7. Interaction effect of inter row spacing and varieties on marketable and unmarketable tuber number

4.7.1. Marketable tuber number per hectare

The main effect of variety and inter row spacing and their interactions significantly ($P < 0.05$) affected marketable tuber number (Figure 6 and Appendix 3). The largest marketable tuber number (705,357) was scored when Gudene variety planted at inter row spacing of 60 x 30cm and Whereas, the smallest marketable tuber number (211,111) was observed from local variety planted at inter row spacing of 50 x 30 cm. The highest (527,381) marketable tuber number per hectares was scored at interaction of inter row spacing (70 x 30 cm) and variety Belete. Variety Gudene and Belete produced their highest marketable tuber number per hectare planted at inter row spacing of 60 x 30cm. The effect shows that optimum inter row spacing (60 x 30 cm) increase marketable tuber number per hectare. The effects indicate that optimum inter row spacing reduced the numbers of unmarketable tuber number per hectare. These may be because of the actuality that at optimum inter row spacing the plants appearance fewer competition for resource and resulted in medium sized tubers which are marketable. The result harmony with the finding of (Harnet *et al*., 2014; Kantona *et al*., 2003) reported that were pointed out that number of marketable tuber yield increase significantly as optimum inter row spacing and tuber yield is increase. This is due to plants appear fewer competition and resulted in highest tubers numbers which are marketable tuber number per hectare.

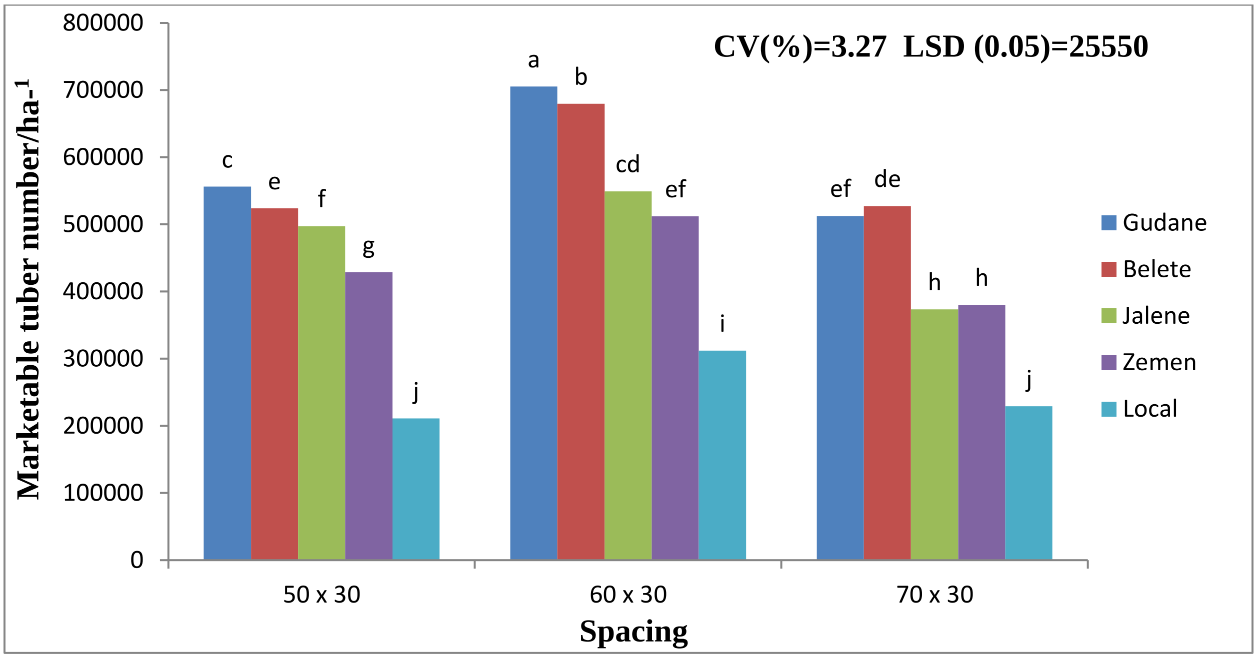

Figure 6: Interactions effect of inter row spacing and variety on marketable tuber number in potato

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.7.2. Unmarketable tuber number per hectare

The analysis of variance revealed that the main effect of variety and inter row spacing and their interactions significantly ($P < 0.05$) influenced unmarketable tuber number (Figure 7 and Appendix 3). The highest (52,777) unmarketable potato tuber number per hectare was scored from local variety planted at inter row spacing of 50 x 30 cm and whereas, the least (23,523) unmarketable potato tuber number per hectare was observed from Belete variety planted at inter row spacing of 70 x 30 cm. The effects indicate that wider inter row spacing reduced the numbers of unmarketable tuber number per hectare. This could be as a result of the actuality that at wider inter row spacing the plants appearance fewer competition and resulted in highest tubers numbers which are marketable. Whereas, at narrow inter row spacing due to extra number of plants per piece of area the plants obtain harsh competition and resulted in undersized and unhealthy tubers and related greater unmarketable tuber per hectare. The result agrees to the findings of (Mvumi *et al*., 2018; Birhanu *et al*., 2016; Tesfa, 2012; Frezgi, 2007) who reported that the closer inter row spacing resulted within the production of greater numbers of small sized unmarketable tubers compare to the wider inter row spacing because there is no intensive competition between wider inter row spacing.

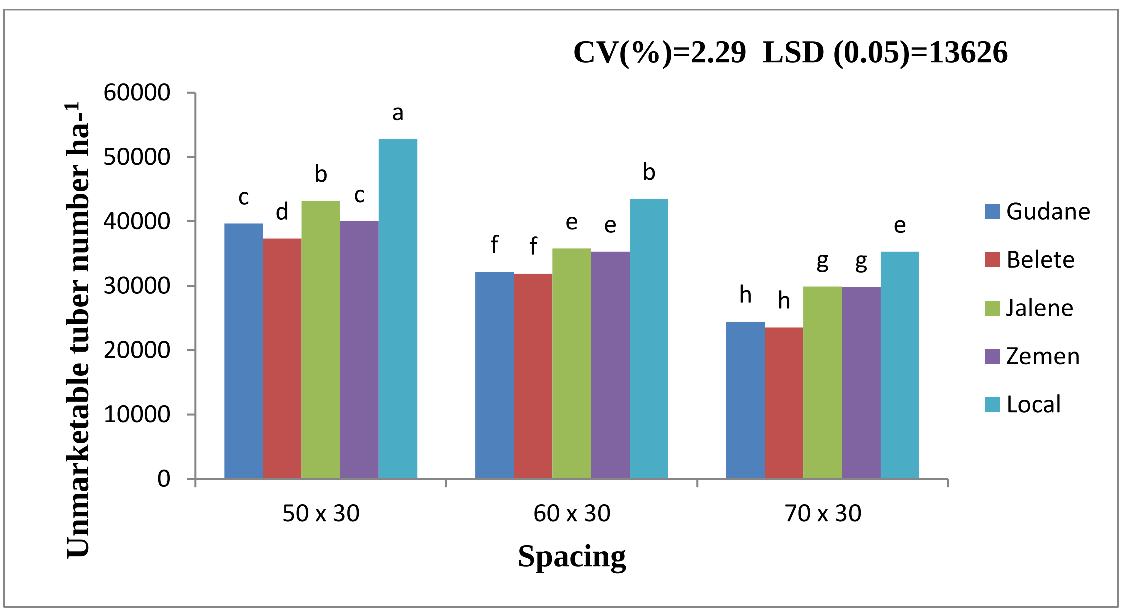

Figure 7: Interactions effect of inter row spacing and variety on unmarketable tuber number in potato

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

4.8. Interaction effect of inter row spacing and variety on potato tuber quality

4.8.1. Dry matter content

The dry matter content was significantly ($P < 0.05$) influenced by the main effect of variety and inters row spacing and their interactions (Table 8 and Appendix 5). The highest (26.7%) potato tuber dry matter content was scored from Gudene variety planted at inters row spacing of 50 x 30 cm. Whereas the smallest (10.91%) dry matter content was scored from local variety planted at inters row spacing of 70 x 30 cm. The results indicate that Zemen and Jalene variety was observed that statically similar results planted at inters row spacing of 50 x 30 cm. The highest dry matter content proportion scored at variety that had highest LAI, it might be the ability to organize more photosynthesis and capable to make more assimilate and it is the channel to sink and in addition the hereditary difference amongst the potato variety in the making of dry matter content (total solids) of tubers. The result was agreements with the findings of (Abebe *et al*., 2020; Lemma *et al*., 2020; Habtamu *et al*., 2016) author's findings that potato variety give unlike tuber dry matter content crossways diverse environment. The difference with esteem to tuber dry matter content is might be because of hereditary difference obtainable among evaluated variety. This result showed that increasing inter row spacing might be the effect in reducing dry matter content. Hence, increasing inter row spacing from 60 to 70 decreased proportion of tuber dry matter content from 15.02 to 13.03. This result is in harmony with the findings of (Mangani *et al*., 2015; Getachew *et al*., 2013) who reported that tuber dry matter content percentages decreased with increased of inter row spacing. These indicate that there was increased dry matter content with increasing plant density and inter row spacing became narrower.

4.8.2. Specific gravity

The analysis of variance indicates that specific gravity significantly (P< 0.05) affected by the main effect of variety and inters row spacing and its interactions (Table 8 and Appendix 5). The highest (1.091) specific gravity was obtained from Gudene variety planted at inter row spacing of 70 x 30 cm. The smallest (1.011) were recorded from local variety planted at inter row spacing of 50 x 30 cm. The lowest specific gravity (1.044) was scored from the local variety planted at inter row spacing of 70 x 30 cm. This might be by reason of the reality that specific gravity is dependent on the hereditary composition of variety and inter row spacing. This is in harmony with the report of (Getachew *et al*., 2013) that well-known that the smallest specific gravity is a varietal attribute can be challenged by inter row spacing and genetic makeup of variety. Also according to Wassu (2017) who described that tuber specific gravity was challenged by hereditary and environmental factor. Increasing inter row spacing was attributed to the less competition among the plants for nutrition. This result agrees with the findings of (Getachew *et al*., 2013) as for the result of diversity however, this important parameter is challenged by a many factors including variety, plant density, nutrition, planting time, seed quality and many others. A fall is in highest specific gravity across all varieties could be accounted for by the intensive competition among the plants for nutrition. Accordingly to (Tesfaye *et al*., 2013) tuber specific gravity is significant effect of dry matter and starch content in potato tuber. They also found out that increasing inter row spacing also specific gravity increased and distressing specific gravity completed that different varieties have different specific gravity.

4.8.3. Total starch content (%)

The results revealed that highly (P < 0.05) significant in response to the main effect of variety and inter row spacing and the interaction of total starch content (Table 8 and Appendix 5). The highest

(17.00%) total starch content of potato tuber from Belete variety planted at inter row spacing of 70 x 30 cm. Whereas, the lowest (4.03%) was scored from local variety planted at inter row spacing of 50 x 30 cm. The difference with esteem to potato tuber total starch content is might be because of hereditary difference obtained among tested variety. The result is harmony to the finding of (Tsegaye 2014; Storey and Davies, 1992) who reported that the total starch content of potato tubers is significantly affected by potato hereditary and assortment of variety. In this studied, the result indicated that increasing inter row spacing might be the result in increased of total starch content of potato tuber. The result agrees with the finding of (Tsegaye, 2014; Kirkman, 2007) who reported that plant density incrementing total starch content was decreased in every plant but reduced plant density also total starch content increasing. Nelson and Shaw (1976) reported that potato tubers with high specific gravity were noted to have high total starch content and they tended to be mealy in texture and to slough when cooked. The specific gravity was also positively and significantly correlated with total starch content. These indicate that factors that lead to increase the specific gravity may also increase the total starch content. Specific gravity is determine of preference for estimate dry matter and total starch content and finally for determining the processing quality of potato variety (Tesfaye *et al*., 2013). Potato varieties with a starch content of 13% and above are the mainly ideal for processed yield (Kirkman, 2007). Thus, from the tested variety, Gudane and Belete had total starch content of 13% and above showing that they are well for processing.

Table 8: Interactions effect of inter row spacing and variety on dry matter and total starch content and specific gravity in potato

Variety	Spacing (cm)	Dry matter content (%)	Specific gravity (g)	Total starch content (%)
Gudene	50 x 30 cm	26.700[a]	1.0370[f]	11.233[e]
	60 x 30 cm	23.000[c]	1.0637[c]	12.667[d]
	70 x 30 cm	18.563[e]	1.0927[a]	15.300[b]
Belete	50 x 30 cm	24.667[b]	1.0287[g]	11.367[e]
	60 x 30 cm	22.667[c]	1.0600[d]	13.633[c]
	70 x 30 cm	16.767[f]	1.0850[b]	17.000[a]
Jalene	50 x 30 cm	19.233[d]	1.0197[i]	8.467[g]
	60 x 30 cm	16.167[fg]	1.0387[f]	11.133[e]
	70 x 30 cm	13.867[h]	1.0637[c]	12.900[d]
Zemen	50 x 30 cm	19.333[d]	1.0197[i]	8.900[g]
	60 x 30 cm	17.233[ef]	1.0357[f]	10.167[f]
	70 x 30 cm	15.007[gh]	1.0590[d]	11.600[e]
Local	50 x 30 cm	12.210[i]	1.0110[j]	4.033[j]
	60 x 30 cm	11.061[i]	1.0187[i]	4.967[i]
	70 x 30 cm	10.913[i]	1.0440[e]	6.667[h]
LSD (0.05)		1.4418	0.0342	0.6362
CV %		4.48	0.19	3.57

Note: means with similar letters (s) in a column are not- significantly different at 5% level of significance. LSD: least significant difference and CV: coefficient of variation.

5. SUMMARY AND CONCLUSION

Potato *(Solanum tuberosum L.)* is one of the most important food crops as it is the source of food, employment and income in developing countries. Optimum plant density is one of the most important practices in potato production management, as it affects seed cost, plant growth, yield and quality of the crop. When a given variety is grown at optimum plant density, it performs well through efficient utilization of moisture, nutrients and light. The current experiment was conducted in Southern Nations, Nationalities, and Peoples` Regional State (SNNPRs), Hadiya zone Misrak Badewaccho district in Wera gera Keble FTC (Farmer Training Center), during the year 2022 G.C main cropping season to elucidate the response of potato variety to different inter row spacing and recommended optimum inter row spacing for potato production in the area. A factorial arrangement consisting of five potato variety (Gudene, Belete, Jalene, Zemen and Local) and three plant spacing (50 x 30 cm, 60 x 30 cm and 70 x 30 cm) was laid out in a randomized complete block design (RCBD) with three replications. Data were collected on phenology, growth, yield and yield component and tuber quality related traits and subjected to appropriate statistical analysis.

Phenology parameters: - days to 50% emergence was significantly ($P<0.05$) affected by variety, whereas days to 50% flowering was significantly ($P<0.05$) affected by variety and inter row spacing and their interaction. Days to 90% maturity was significantly ($P<0.05$) affected by both main factor. Of the growth parameters, Stem number per hill was significantly affected by main effect of variety and plant height, leaf number per plant, leaf area index and harvest index was significantly ($P<0.05$) affected by the main factor but not its interactions and leaf area was significantly influenced by main effect of inter row spacing and variety and its interaction. Yield and yield component parameters: - total biomass, total tuber yield, tuber number per hill and tuber size distribution were significantly affected by main effect of inter row spacing and variety but not by their interactions. Marketable and unmarketable tuber yield and marketable and unmarketable tuber number was significantly affected by main effect of inter row spacing and variety and its interactions. Tuber quality parameters (tuber dry matter, specific gravity and total starch content) were significantly influenced by the main factor of variety and inter row spacing and its interactions.

On the other hand local variety was scored the longest days to 50% emergence, days to 50% of flowering and days to 90% of maturity and the shortest days was scored from zemen variety. The highest stem number per hill, plant height, leaf number per plant, leaf area, leaf area index, harvest index, total dry biomass, total tuber yield, tuber number per hill, dry matter content, specific gravity, marketable tuber yield and marketable tuber number was scored from Gudene variety whereas, lowest data was recorded from local variety. The highest, stem number per hill, plant height, leaf number per plant, leaf area, tuber number per hill, total dry biomass, specific gravity and total starch content recorded at inter row spacing (70 x 30 cm). The highest interactive effects was scored from marketable tuber yield from Gudene (36.00t/ha^{-1}) and Belete (34.67t/ha^{-1}) variety and inter row spacing (60 x 30 cm) whereas, lowest effect was recorded from local (12.83t/ha^{-1}) variety and at inter row spacing (50 x 30 cm). Therefore, from this study, it can be concluded that Gudene and Belete varieties and at inter row spacing (60 x 30 and 70 x 30 cm) resulted in highest marketable potato yield. The results obtained in this study are based on single season and single location it should be repeated to validate this result before recommending to the area.

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Appendix Table 1: Mean square for days to 50% emergence, days to flowering and 90% maturity

Source of variations	DF	Mean Square		
		Days to 50% emergence	Days to 50% flowering	Days to 90% maturity
Replications	2	0.8000	0.139	1.089
Variety	4	35.672**	106.325**	838.078**
Spacing	2		50.206**	147.289**
V*S	8	0.0847ns	1.775**	1.511ns
Error	28	0.1036	0.222	1.137
CV %		2.09	0.88	1.05

*****and ****** significant, highly significant difference at 5%. Ns: non- significant

Appendix Table 2: Mean square for stem number per hill, plant height and leaf number per plant

Source of variations	DF	Mean Square: Stem number per hill	Plant height (cm)	Leaf number per plant	Leaf area (cm)	Leaf area index	Harvest index (%)
Replications	2	0.0629	8.09	22.4	1.511	0.02346	0.00254
Variety	4	11.557**	2231.21**	12179.8^{ns}	688.970**	2.87399**	0.13352**
Spacing	2		490.82**	2601.2**	242.634**	2.27487**	0.09405**
V*S	8	0.1126^{ns}	8.53^{ns}	207.0^{ns}	12 .667**	0.17273^{ns}	0.00312^{ns}
Error	28	0.4415	1.51	41.4	0.664	0.1795	0.007
CV %		13.59	1.70	3.22	2 .05	4.39	4.24

*****and ****** significant, highly significant difference at 5%. Ns: non- significant

Appendix Table 3: Mean square for total tuber yield ha^{-1}, marketable and unmarketable yield ha^{-1}, tuber number per hill, marketable and unmarketable tuber number per ha^{-1} and total biomass yield

Source of Variations	DF	Mean Square						
biomass		Total tuber yield t/ha	Marketable yield t/ha	Unmarketable yield t/ha	Tuber number per hill	Marketable tuber number	Unmarketable tuber number	Total yield
Replications	2	7.550	6.217	0.1556	0.2302	2.6028	2.37642	55.4
Verities	4	231.589**	454.522**	38.8806**	46.3808**	1.6891**	2.3228**	12588.1**
Spacing	2	42.617**	62.817**	37.9389**	40.2096**	8.7040**	7.3598**	9548.5**
V*S	8	6.422^{ns}	6.581**	1.1056**	1.9801^{ns}	3.434**	6.115*	299.6^{ns}
Error	28	1.401	0.979	0.2329	0.0817	2.334	6.6337	63.1
CV		3.89	3.83	10.32	2.62	3.27	2.29	3.83

*and ** significant, highly significant difference at 5%. Ns: non- significant

Appendix Table 4: Mean square for small size tuber, medium and large size tuber

Source of Variations	DF	Mean Square		
		Small size tuber %	Medium size tuber %	Large size tuber %
Replications	2	0.65	0.076	3.200
Variety	4	1239.39**	527.917**	157.896**
Spacing	2	330.98**	93.364**	58.9270**
V*S	8	0.99ns	6.058ns	4.31760ns
Error	28	0.24	0.704	0.04157
CV %		2.02	1.19	3.58

*and ** significant, highly significant difference at 5%. Ns: non- significant

Appendix Table 5: Mean square for dry matter content, specific gravity and total starch content

Source of Variations	DF	Mean Square		
		Dry matter content (%)	Specific gravity (g)	Total Starch content (%)
Replications	2	1.471	2.1565	0.188
Verities	4	181.257**	2.272**	105.161**
Spacing	2	110.009**	7.575**	57.115**
V*S	8	6.922**	1.122**	1.379**
Error	28	0.743	0.061	0.145
CV %		4.84	0.19	3.57

*and ** significant, highly significant difference at 5%. Ns: non- significant

BIOGRAPHICAL SKETCH

The author was born in Misrak Badawacho Woreda Shone Town, Hadiya Zone of SNNP Regional State Ethiopia in 1989. He attended elementary education at the Shone Junior School from 1989 to 2002, high school, preparatory education at Shone Junior secondary, and a preparatory school from 2003 to 2006. In 2007, he joined Wolaita Sodo Tevet Collage and graduated with the Diploma in plant sciences in July 2009. After graduation, he was employed in Misrak Badawacho Woreda Agriculture Office as extension worker in the field 2010. He served as extension worker in the field of plant Sciences. In 2013, He joined Wolaita Sodo University and graduated with the BSc Degree in plant Sciences in December 2017. After graduation, he was employed in Misrak Badawacho woreda agriculture office he served as expert. In 2021, He joined School of Graduate Studies (SGS); know Postgraduate Programs Directorate at Hawassa University to pursue a study leading to the Degree of Master's of Science in Agriculture (Horticulture).