EFFECT OF SEED TUBER SIZE AND INTRA ROW SPACING ON YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.) VARIETIES AT NONO BENJA, JIMMA ZONE

M.Sc. THESIS

By

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EFFECT OF SEED TUBER SIZE AND INTRA ROW SPACING ON YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.) VARIETIES AT NONO BENJA, JIMMA ZONE

Thesis Submitted to School of Graduate Studies Jimma University, College of Agriculture and Veterinary Medicine in Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture (Vegetable Science)

By

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DEDICATION

This thesis is dedicated to my wife, Fedashi Jembare for her unlimited support with great love and tolerance to my long stay during the study period.

BIOGRAPHICAL SKETCH OF THE AUTHOR

The author, Miressa Regasa Turi, was born on September 05, 1984 in Oda Liban Kebele, Dano District, West Shoa Zone of Oromia National Regional State. He attended Elementary School at Doreni and Benja, Junior Secondary at Nono and Secondary Schools at Ambo and Gedo. Following the completion of High School, he joined Jimma University College of Agriculture and Veterinary Medicine in September 2005 and graduated with BSc Degree in Horticulture in June, 2008. After graduation, he was employed by the Oromia Bureau of Agriculture as an agronomist at Nono Benja District (Jimma Zone) where he has been served for four years. In September 2012, he joined the graduate studies program of Jimma University College of Agriculture and Veterinary Medicine to pursue his M.Sc. study in the field of horticulture specialization in Vegetable Science.

STATEMENTS OF THE AUTHOR

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
EARO	Ethiopian Agricultural Research Organization
g	gram
ha	hectare
HARC	Holleta Agricultural Research Center
hrs	hours
JARC	Jimma Agricultural Research Center
JZOA	Jimma Zone Office of Agriculture
LSD	Least Significant Difference
masl	Meter above sea level
mm	Millimeter
MOARD	Ministry of Agriculture and Rural Development
SAS	Statistical Analysis System
t/ha	tons per hectare
CSA	Central Statistical Authority
NBAO	Nono Benja District Agriculture Office

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EFFECT OF SEED TUBER SIZE AND INTRA ROW SPACING ON YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.) VARIETIES AT NONO BENJA, JIMMA ZONE

ABSTRACT

A field experiment was conducted at Nono Benja District from December 2013 to May 2014 under irrigation to assess the response of different sizes of seed tubers and intra row spacing on yield and quality of potato varieties. The treatments consisted of factorial combination of two varieties (Jalenie and Gudenie), five levels of tuber sizes (20-35, 36-50, 51-65,66-80 and 81-95g) and five levels of intra row spacing (20, 25, 30, 35 and 40 cm). The treatments were arranged in a split-split plot design with three replications. There were a significant interaction effect of varieties, intra row spacing and tuber sizes ($P<0.05$) on plant height, number of main stems per plant, average tuber weight, tuber number per plant, total tuber yield, marketable tuber yield, unmarketable tuber yield, large tuber mean yield, medium tuber mean yield, small tuber mean yield. Variety by tuber size and intra row spacing was also influenced dry matter content and tuber specific gravity.The interaction effects of intra row spacing and seed tuber size was significantly ($P<0.05$) influenced the number of days to emergence. The days to flowering was also significantly ($P<0.05$) influenced by interaction effect of variety and intra row spacing. The highest plant height (80.38 cm) was recorded with variety Gudenie using tuber size of 66-80 g and planted at intra row spacing of 35 cm. The highest (9.79) number of main stems was recorded with variety Jalenie using tuber size of 81-95 g and planted at intra row spacing of 40 cm.The highest total tuber yield (24.84 t/ha) was recorded from Jalenie variety with tuber size 66-80 g and planted at intra row spacing of 25 cm. The highest (10.18 t/ha) larger tubers was recorded with variety Gudenie using tuber size of 66-80 g and planted at 25 cm. Variety Jalenie with tuber size of 66-80 g and planted at 25 cm produced the highest (8.04 t/ha) medium sized tubers. The highest small tuber (8.59 t/ha) was recorded from both varieties with intra row spacing of 20 cm and tuber size 81-95 g. Variety Gudenie planted at intra row spacing of 40 cm gave higher (19.98%) dry matter content and variety Gudenie using tuber size of 66-80 g gave higher (20.61%) dry matter content. The higher (1.077) tuber specific gravity was obtained with variety Gudenie planted at intra row spacing of 35 and 40 cm and also the higher (1.074) tuber specific gravity was registered with variety Guidene using tuber size of 66-80 g and/or 81-95 g and planted at intra row spacing of 40 cm. Number of main stems (r = 0.15), tuber number per plant (r = 0.63**), average tuber weight (r = 0.23**), marketable tuber yield (r =0.95**) and unmarketable tuber yield (r = 0.18*) was positively correlated with total tuber yield. Average tuber weight (r = 0.36**) positively associated with marketable tuber yield, small tuber (r =-0.40**), medium tuber (r = 0.44*). Large tuber negatively associated with dry matter content (r = -0.39**) and tuber specific gravity (r = -0.34**). Smaller tuber was positively correlated with Dry matter content (r = 0.50**) and tuber specific gravity (r = 0.56**). Dry matter content positively associated with tuber specific gravity (r = 0.88**). Generally, the use of intra row spacing 25 cm and tuber size of 66-80 g are advisable for the production of higher tuber yield of variety Jalenie, and variety Gudenie suggested for quality potato production at Nono Benja area.*

***Key words**: Tuber Size, Intra Row Spacing, Potato Varieties, Yield, Quality, Ethiopia.*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is a world food crop ranked fourth after wheat, rice and maize having a production of morethan 325.3 million tons that was harvested from the total area of 19.33 million hectares (Tesfaye *et al.,* 2012). It is grown in more than 100 countries under temperate, subtropical and tropical conditions (FAO, 2010b) and considered as the most important tuber crop contributing to human nutrition and highly dependable for food security and also had economic benefits to the growers (Hirpha*et al*., 2010; Badoni and Chauhan, 2011*).* It provides quality proteins and a substantial amount of vitamins, minerals and trace elements (Masarirambi *et al.,* 2012). Potato is a productive crop in terms of yields of edible energy and quality of protein per unit area and per unit of time fitting into intensive cropping systems (Bezabih and Mengistu, 2011).

Potato is introduced into Ethiopia in 1858 by a German scientist Wilhelm Schimper, and subsequently adopted by growers over a period of several years (Nunn and Qian, 2011). In Ethiopia, potato is a high potential food security crop due to its high yield potential per hectare and nutritious tuber (Ayalew *et al.,* 2014). Ethiopia is endowed with suitable climatic and edaphic conditions for high quality potato production (Tibebu *et al.,* 2014)**.** In Ethiopia, the total area under potato production is 74,934.57 ha and annual production is 863,347.79 tons with an average yield of 11.5 t/ha (CSA, 2013). According to MOARD (2009) the average yields of the crop on research and farmer's fields is 40 and 20 t/ha, respectively. The low national average yield of potato is attributed to biotic and abiotic factors among which lack of optimal agronomic practices including poor seed tuber size, plant density, lack of improved crop variety and high-quality seed potatoes, late blight and inadequate pest management practices are the prominent ones (Tsegaw, 2005; Habtamu *et al*., 2012).

Seed tuber size and intra row spacing are among the major factors affecting the production and productivity of potato (Berihun and Woldegiorgis, 2012; Masarirambi *et al.,* 2012). The amount of seed tuber used per ha is quite bulky, which is about 1.8 to 2.2 t/ha (EARO 2004; MOARD, 2009); and hence inappropriate seed tuber size and intra row spacing results in ware potatoes wastage (Lutaladio *et al.,* 2009; Badoni and Chauhan, 2011). The cost of seed or the seed rate is directly associated with the size of seed tubers, and influenced by the size of seed and intra row spacing (Hossain *et al*., 2011). Potato Seed rate might be reduced to less than 40% if optimum size seed tubers are used (Singh and Sharma, 2008). Total tuber yields increased as increasing in plant density while quality of tubers decreased (Masarirambi *et al.*, 2012). On the other hand, the different tuber size results in different yield and quality of potato. The farmers use even under size seed tubers which leads to production of low yield and poor quality potato. The yield performance and quality of potato tuber from large seed tuber size was higher than small seed tuber size (Tibebu *et al.*, 2014). The seed potato tuber requirement especially in developing countries is voluminous; it accounts for 40 to 75 % of the total potato production cost (Khalafalla, 2001; Kakuhenzire *et al*., 2005; Singh and Sharma, 2008). The high cost and unavailability of planting materials calls for efficient use of seed tubers to have profitable production (Babaji *et al.*, 2009). Timing of sprout development, plant establishment, tuber initiation, tuber bulking, and tuber maturation growth stages varies depending upon size of seed tubers and intra row spacing used.Small size tubers delayed emergence and result in low sprout vigour and number (Lommen, 1994; Lommen and Struik, 1994), and might be a progeny of an infected mother plant and thus infected mother plants usually give small tubers (Struik and Wiersema, 1999).

Potato intra row spacing is important due to the increased opportunity to manipulate plant population to target a marketable tuber size, however, narrow intra row spacing results in lowering average tuber size (Tarkalson *et al.*, 2011). The performance of seed is related to size uniformity and optimum intra row spacing to increase yields and ensure uniform planting (Ayyub *et al.*, 2012). Use of small size seed is a major problem in Ethiopia (Gildemacher *et al.*, 2009). Woldegeorgis *et al.* (2001) reported that farmers have been using inferior size tubers from own harvest which contributed to the build-up of diseases and low yield. According to Gildemacher *et al*. (2009) 72%, 66% and 63% of growers in Degem, Jeldu and Banja Districts, use medium-size tubers respectively.

Intra row spacing on the other hand, depends upon a number of factors such as variety, soil type, fertilizer rate, and irrigation as well as weather conditions (Endale and Woldegiorgis, 2001). Potato tuber size and different intra row spacing were suggested in the production of good quality potato tubers at different parts of Ethiopia (Bikila *et al.*, 2014). Tibebu *et al.* (2014) investigated the effect of different tuber sizes on the performance of different Potato varieties at Wolaita Zone of Southern Ethiopia and found no significant influence of tuber size. Seed tuber size of 45-55 mm diameter (90 g) suggested for ware potato production at Adet Agricultural Research Center (Tesfaye *et al.*, 1999). Harnet *et al.* (2014) also concluded the narrow intra row spacing of 20 cm with variety Jalenie produced higher potato tuber yield and marketable yield per hectare than other intra row spacing at southern zone of Tigray.

In Nono Benja District, potato production was started long years ago by potato producing farmers. Despite its low productivity potato is becoming an emerging cash vegetable crop, which should be get attention in the area after cereals (NBAO, 2012). Potato productivity in the area was even less than the regional and national average yield and poor quality that might be attributed to variations in seed size, intra row spacing and related agronomic practices (JZOA, 2012). Growers use bulk seed that is either large or small seed tubers, thus resulting in non-uniform seed tubers. Few years ago, Jimma Agricultural Research Center (JARC) demonstrated Jalenie and Gudenie varieties on the farmer's field in the area. Although JARC introduce the varieties to the area, growers have been using inappropriate intra row spacing and variable seed tuber size for potato production due to lack of recommended intra row spacing for the area. The possibility of promoting potato yield depends much upon a proper consideration of optimum number of plants per unit area/plant population. However, farmers in the study area were not using either of the recommendations since it may not fit to the conditions of that specific area. Hence, it is important to investigate the suitable intra row spacing and tuber size for the area, because, no research has been conducted in this regard so far in the area to identify the effects of seed tuber size and intra row spacing on yield and quality of potato. Thus, it was hypothesized that different seed tuber size and intra-row spacing would result in different yield and quality of potato varieties. Therefore, the objectives of the study were as follows:

General objective

- To increase the yield and quality of potato (*Solanum tuberosum* L.) production at Nono Benja District.

Specific objective

- To evaluate the effects of seed tuber size and intra row spacing on yield and quality of potato (*Solanum tuberosum* L.) varieties at Nono Benja.

2. LITERATURE REVIEW

2.1. Effects of seed tuber size and intra row spacing on phenology and growth of potato

2.1.1. Days to 50% emergence

Days to 50% emergence was the time taken place starting from planting to bearing or emerging. Varieties were different in days to 50% emergence, in which variety Desiree was emerged 2.5 days earlier than variety Cardinal because of genetically difference between the two varieties (Ahmed *et al.,* 2000). According to Bewuketu (2012) variety Gudenie took significantly longer days to 50% emergence (19.2) than variety Jalenie which took 16.87 days. Helen *et al.* (2014) indicated among investigated varieties, Mashenadima required the highest number of days to reach 50% emergence, closely followed by Batte and Jarso varieties.

Potato seed tubers emerged relatively faster at a wider intra row spacing (30 and 40 cm) than in closer intra row spacing (Bikila *et al.,* 2014). Seed sizes can influence the length of time from planting to emergence; the larger seed sizes emerged earlier than small seed sizes (Mwansa, 2002). Larger seed tubers were associated with large embryo axis, leaf primordial and cotyledon area, and had slightly longer and thicker sprouts at planting time and this contributed to earlier germination and to establish faster since the tubers were not yet photosynthesizing but were relying solely on the supply of metabolites from the mother tubers (Masarirambi *et al.,* 2012). According to Patel *et al.* (2008), who reported the bigger seed tuber (51-70 g) showed earlier days to 50% emergence compared to smaller seed tuber (31-50 g). The smaller seed tuber size required longest time to complete days to emergence, which indicates the larger seed tubers gave earlier emergence, and gave maximum crop coverage and growth (Sultana *et al.,* 2001).

2.1.2. Days to 50% flowering and physiological maturity

Days to 50% flowering and physiological maturity was influenced by variety. Helen *et al.* (2014) conducted a research on varieties Jarso, Daddafa, Chala, Gabbisa, Batte, Chiro and Zemen and obtained all significantly influenced days to 50% flowering and physiological maturity. The same authors concluded that the varieties named Mashenadima required the longest duration of time to reach 50% flowering and in case of 50% maturity Daddafa required the longest duration of time by about 31% than early-matured variety Chiro. However, varieties as well as days to physiological maturity had no effect on days to 50% flowering (Tibebu *et al.*, 2014).

Days to 50% flowering was delayed at widest than closest intra row spacing due to higher competition of plants for resources in the closer intra row spacing that lead the plants to stress and ultimately the plants flower early instead of prolonged vegetative growth (Tesfaye *et al.*, 2012). Decreasing intra row spacing significantly reduced days to flowering and fruit setting in tomato plant (Ismail and Mousa, 2014). Potato tubers planted in a wider intra row spacing got sufficient light that promote the transition of vegetative stage to the reproductive stage than those planted in closer intra row spacing (Bikila *et al.,* 2014).

2.1.3. Plant height

The difference in plant heights of the varieties might be attributed to genetic differences, which might have led to the variable performances in growth and development, and the fertility of soil enhancing effects on the vegetative growth of plants by increasing cell division and elongation and the varietal variability to absorb nutrients from the soil (Helen *et al.*, 2014). Tibebu *et al.* (2014) reported that plant height of variety Gudenie was higher plant height of variety Jalenie and others, but it is not influenced with different tuber sizes under study. Bewuketu (2012) reported the Plant height was affected by variety and obtained variety Gudenie was taller (77.77cm) than variety Jalenie (69.14 cm).

Large tubers were proved in relation to better plant height foliage coverage and maximum vegetative growth (Hossain *et al.*, 2011). Plant heights in different environmental condition ranged from 45.96 to 63.63 cm and 40.12to 62.81 cm, respectively (Mahmud *et al.,* 2014). Patel *et al.* (2008) indicated that large size seed tubers (51-70 g) resulted in higher plant eight and growth than small tuber seeds.

Densely populated plants (closer inter and intra row spacing) show intensive competition which leads to decrease in plant heights (Bikila *et al.*, 2014). In contrary, Tesfaye *et al.* (2012) reported the highest plant height (66.1 cm) at the closer intra row spacing of 10 cm and 20 cm however, the shortest plant height (62 cm) was observed at 30 cm and 40 cm intra row spacing foliage coverage and maximum vegetative growth. This is due to the presence of higher competition for sunlight among plants grown at the closer intra row spacing. Sharma and Singh (2010) indicated that the increase in plant height was significantly more with double plant density. The use of 20 cm intra row spacing gave the tallest but less robust plants, because there was competition between plants, for solar radiation, which led to etiolation; plants grew narrower with less branching than 40 cm intra row spacing (Daure *et al.*, 2014).

2.1.4. Number of main stems per plant

Potato tubers show a wide range of variation and possess a variable number of growing buds arranged in groups over their surface (Mulubrhan, 2004). Potato tubers contain two types of buds, namely apical and lateral buds (Allen, 1978).

The number of eyes per tuber was reported to be dependent on the size of tubers (Allen, 1978). Varietal difference was also reported to influence eye number per tuber (Lynch and Tai, 1989). Although variety, tuber size or other factors exert their influence on the number of eyes on tuber surface, there seems to be only one eye on a tuber that develops into stems and also no difference exists between eye types (apical or lateral) in their yield potential (Allen, 1978). The same Author also confirmed the performance of different eyes within tubers of the same size and total eye number by dissecting out the eyes to produce single eye tubers, therefore, revealed that differences between eye positions caused small differences in numbers of stems and tubers, and tuber yield.

The number of main stems per plant was reported to be under the influence of variety, intra row spacing, and seed tuber size, number of viable sprouts at planting and growing conditions (Morena *et al.*, 1994). Allen (1978) reported the importance of increasing the stem number per plant for increased graded and total tuber yield. Similarly, Gray and Hughes (1978) observed close relationships between the number of main stems or aboveground stems and total yields and graded tuber yields. These investigators claimed that high stem number per plant favored high tuber yield through effect on haulm growth and tuber number per plant. Abbas (2011) reported that the foliage growth as well as variety development and performance might be the causes for variation of small size tubers among different varieties. Rajadurai (1994) found that the number of stems produced per tuber increased with increasing tuber sizes and intra row spacing, and verifies that the medium size seed tubers significantly increased stem numbers over small size seed tubers.

2.2. Influences of seed tuber size and intra row spacing on potato tuber yield

The exact number of plants per hectare was determined by seed tuber size, plant spacing, variety and the end use of the potato. Farmers preferred Small- and medium-sized seed tubers (Rykbost and Locke, 1999). Planting large seed tubers size increased the tuber number and yield per plant over small size tubers (Islam *et al*., 2012). In Ethiopia the optimum seed tuber size is 40–60 g, which provides optimum tuber yield (MOARD, 2011). The seed tuber size of 50 – 60 g produces more number of medium tubers, which was better in potato production in case of marketable (Farahvash and Iranbakhsh, 2009). Seeds larger than 80 g increase seed costs (FAO, 2010a). According to Lung'aho *et al.* (2007) the quantity of seed tubers required by a farmer depends on the size of the seed tubers to be planted which ranged from 1.75–2.0, 2.25–2.5, and 3.0–3.25 t/ha for small-, medium-, and large-sized tubers, respectively, at a spacing of 75 x 30 cm. Roy *et al.* (2015) conducted on seed tuber sizes of 10-20, 20-30, 30-40 and 40-50 g; intra row spacing of 10, 15 and 20 cm and observed there were a significant differences among yield variables. The inappropriate intra row spacing can affects the tuber quality and marketable tuber size of potato since it is correlated with plant populations (Harnet *et al.*, 2014). The absence of optimal intra row spacing practices could significantly reduce total tuber yield up to 50%, therefore optimization of intra row spacing is one of the most important agronomic practices of potato production (Endale and Woldegiorgis, 2001).

Arsenault and Christie (2004) reported that the size of seed tubers could strongly influence yield variables of potato. Tuber seed size 51-70 g resulted in higher tuber yield, which might be due to quick plant emergence and better plant growth (Abbas, 2011). Tibebu *et al.* (2014) reported that the highest yield of total potato tuber (32.61 t/ha) was obtained from large tuber size (>75 g) while the minimum was observed (28.13 t/ha) at small tuber size (<39 g). However, the benefits of using larger sized seed diminish as the size of seed increases above 70 g (FAO, 2010a). The number of eyes per tuber increases with tuber weight though does the number of sprouts or stems per seed tuber and this influences tuber yield (Wei *et al.,* 1997). Tuber yield decreased significantly as seed size decreased from very large tubers to small tubers (Masarirambi *et al.,* 2012). According to EARO (2004) the recommended amount of seed tubers used are bulky (1.8-2.0 t/ha).In principle larger seed sizes result in higher total yield than smaller sizes, but growers prefer to plant small, seed tubers (single-drop seed) (FAO, 2010a). According to Akbari *et al.* (2013) the most suitable size for seed tubers are seed ranging between 50-60 g weight. The benefits of using large size seed diminish as the size of seed increases above 70 g (FAO, 2010a). Tubers size between 30 and 50 g were economical and gave the highest yield (Chandy, 2012). Seed size for optimal productivity ranges from 40 to 85 g (Bohl and Johnson, 2010).

The increased yield by high plant population results in reduced large tuber size yield. The large size tubers increased with spacing increase (Khalafalla, 2001). Higher plant densities lead to early canopy closure. Nevertheless, while this increase yield, some of other factors may reduce quality because high planting densities increase tuber numbers per square meter and reduce tuber size (Masarirambi *et al.,* 2012). In case of using standard size seed tubers, the main determinant of stem density is planting distance since each plant will have almost same number of stem (Gulluoglu and Arioglu, 2009). Kumar *et al.* (2012) reported that the total tuber yields in potato increase with closer spacing. The same authors also identified that the variation in intra-row spacing can also affect tuber size distribution. For any given potato variety, information on intra-row spacing is required to optimize yields of marketable size tubers (Kumar *et al.*, 2012). According to Bohl *et al.* (2011) total tuber yield increased as seed tuber size increased from 42 g (34.1 t/ha) to 85 g (37.4 t/ha) planted at 20 cm intra row spacing. The same Authors reported that the total tuber yield decreased as intra row spacing increased from 20 cm to 40 cm; at the 40 cm intra row spacing, 42 g seed tuber yielded 26.3 t/ha compared with 32.7 t/ha for 85 g seed tuber, an increase of 6.4 t/ha. Similarly, Tesfaye *et al.* (1999) reported the maximum total tuber yield (28.3 t/ha) and marketable tuber yield (22.6 t/ha) from seed tuber size of 80-90 g. Intra row spacing alters the yield of vegetable crops, the majority of potato tuber quality variables were preferable at 30 cm intra row spacing (Tesfaye *et al.*, 2013).

2.2.1. Number of tubers per plant

According to Allen (1978), number of tubers per plant largely governs the total tuber yield as well as the size categories of potato tubers and the number of tubers set by plants was determined by stem density, spatial arrangement, variety, season and crop management. Increasing stem density over a wide range either by planting larger seed tubers or by more seed tubers for most varieties resulted in increased number of tubers per unit area (Gray and Hughes, 1978). Mahmud *et al.*

(2014) indicated that variety affects significantly the tuber number per plant and obtained tuber number per plant ranged numerically from 5.76 to 10.80 in 2010-11 and 7.23 to 10.42 in 2011-12, respectively.

Bewuketu (2012) reported that variety Jalenie was superior in respect of tuber number per plant; while Guidene produced the minimum number of tubers per plant. The apparent variation could be due to the difference in genetic potential among potato varieties in which the number of stems per plants might have contributed to the difference (Bewuketu, 2012).

Intra row spacing has a large influence on the number of tubers per ha. As seed tubers are spaced closer together, tuber numbers per plant typically decreases. However, because the seed tubers are spaced closer together, the resulting total plant population per ha increases, and the overall tuber number per ha will also likely increase. Without proper spatial arrangement, plant population by itself is of marginal importance in optimizing economic return in potato production (Thornton *et al.,* 2007). Narrow spacing increased the hectare yield and decreased the yield per plant. The large size seed tubers planted at narrow intra row spacing (20 cm) results highest yield (Rajadurai, 1994).

2.2.2. Average tuber weight

Average tuber weight was the third most important yield component contributing to the total tuber yield (Morena *et al.,* 1994; Mulubrhan, 2004). The growth of tuber tissue was occurring both by cell division as well as by expansion in which cell division is more important than cell expansion for tuber growth (Reeve *et al.,* 1973). In addition, Reeve *et al.* (1973) were also able to show tuber growth, after the tubers had reached 30-40 g, was by cell enlargement while cell division had more contribution in earlier stages.

Variety and growth conditions affect average tuber weight (Mulubrhan, 2004). Environmental factors that favor cell division and cell expansion such as mineral nutrition, optimum water supply, etc. enhance tuber size (Reeve *et al.,* 1973). Bewuketu (2012) finding confirmed that variety Jalenie increased average tuber weight as compared to the other local variety. The variation might be attributed to the inherent genetic variation on tuber bulking among potato varieties. The rate of tuber bulking varies among varieties and depends on environmental conditions (Levy and Veilleux, 2007).

The greatest influence of intra row spacing was on average size and tubers per hectare. In general, as intra row spacing increased (plant population decreased) the average tuber size increased and tubers per hectare decreased. Plant population is important due to the increased opportunity to manipulate plant population to target a specific tuber size market. Higher plant populations result in lowering average tuber size (Tarkalson *et al.*, 2011). The increased yields at higher plant density were attributed to the ground covered with green leaves earlier; fewer lateral branches being formed and tuber growth starting earlier (Mwansa, 2002). According to Roy *et al.* (2015) the largest average tuber weight was observed in intra row spacing of 25 cm (48.70 g) followed intra row spacing of 20 cm (44.75 g) and lowest from 15 cm (41.24 g).

2.3. Varietal differences on yield and quality of potato.

Currently 29 potato varieties have been released for cultivation for diverse agro-climatic conditions of Ethiopia (Haverkort *et al.*, 2012). Varieties differ not only as to the percentage of stolons that bear tubers, but also with respect to the pattern of tuberization at different nodes (Ewing, 1997). The traits i.e. dry matter content, specific gravity, starch content, texture, reducing sugars were influenced by variety (Abbas, 2011). Different potato varieties differ markedly in yielding ability. The appearance of foliage growth is characteristics for distinguishing variety from the other (Abubaker *et al.*, 2011).

Most varieties possess either shallow or medium eye depths, which is perfect to reduce losses during peeling and trimming (Abbas, 2011). In a yield trial, improved varieties are far better than local land race varieties in the production of small size tubers and total tubers (Singh, 2005). Farmers apparently consider many factors in selecting varieties (Girma, 2012). The extent of yield and tuber size response to intra-row spacing varies among varieties (Arsenault *et al.*, 2001).

Asmamaw *et al.* (2010) conducted to investigate the influence of variety and growing environment on postharvest quality of seven released potato varieties at Northwest Ethiopia in 2006 and verified that varieties Jalenie, Guassa, and Zengena produced tubers with higher dry matter percentage at all locations than the others. Tsegaw and Zelleke (2002) showed that reproductive growth restricted vegetative growth and reduced tuber yield and quality of potato among varieties. Hassanpanah *et al.* (2009) reported potato size distribution (large, medium and small) significantly affected by variety.

2.4. Influences of seed tuber size and intra row spacing on quality of potato

2.4.1. Tuber dry matter content and specific gravity

As planting density was increased so the dry matter content of the tubers increased. Increases in dry matter content were associated with increases in the disintegration of the tubers when cooked. However, varieties differ in their ability to compensate for wide intra row spacing and reductions in populations (Creamer *et al.,* 1999). Starch is heavier than water, and, therefore, is the primary determinant of tuber density, which commonly referred to as tuber specific gravity. Starch, tuber dry matter content, tuber solids content, and tuber specific gravity are terms used interchangeably when related to tuber processing quality.

The potato growing community and the commercial potato processing industry need potato varieties that combine high tuber yield with high specific gravity (Haynes, 2001). Elfinesh *et al.* (2011) pointed out that the high specific gravity is an indication that the raw potatoes will produce high chip volume due to high dry matter content. Variation in tuber dry matter content might be attributed to varieties inherent difference in the production of total solids. More recently developed potato varieties have shown improvement for traits that are important to the processing industry, such as high specific gravity and chip color (Haynes, 2001).

Tesfaye *et al.* (2012) reported that the dry matter content of potato varieties is highly affected by the variety, cultural and environmental conditions during the growing season. The total dry matter yield of crops depends on the size of leaf canopy, the rate at which the leaf functions and the length of time the canopy persists. A study of dry matter production and distribution to the various plant parts in the course of development is important for the evaluation of the growth rate, productivity and the yield level of potato (Tsegaw, 2005).

Variety, plant population and seed tuber size influence the potato yield and quality (Islam *et al.,* 2012). Quality is one of the most important characteristics of potato and it is dependent on external and internal aspects of the tuber (Tesfaye *et al.,* 2013). The texture of a boiled and baked potato is because of dry matter content as well as specific gravity (Abbas, 2011). In addition to preparation of different kinds of traditional foods, recently potato started to use in small scale processing like chips, crisps and French fries (Elfinesh *et al.*, 2011).

2.4.2. Tuber size category

The size distribution of harvested crop is one of the factors determining its economic value and specific grades are required for specific market outlets (Bekuma and van der Zaag, 1990). Most consumers require big size potatoes since large tubers are required for processing, while medium sized tubers are preferred for home consumption and farmers often used small tubers for seed and home consumption (Govinden, 2006). Tubers less than 35 mm are considered small, those between 35-55 mm are medium and greater than 55 mm are large and tubers which are healthy with a size more than or equal to 35 mm are generally considered as marketable tuber (Hassanpanah *et al*., 2009; Khan *et al*., 2011; Abbas *et al*., 2012). According to Mulubrhan (2004) the tube size categories are based on weights of tubers (small = <50 g; medium = 50 – 75 g; large = >75 g).

Several researchers have reported effects of seed tuber sizes on tuber size category. Kumar *et al.* (2009) reported seed tuber sizes influenced growth and yield, significantly. Effect of different size tubers for a seed crop, it is not only the total tuber yield which is important but yield of different tuber size also has great significance. According to Mulubrhan (2004), the production of potato tuber of a requisite size might be much of economic value for both seed and human consumption. The size of tubers required by consumers depends upon the ease of handling for household purposes and upon the acceptable level of peeling loss (Gray and Hughes, 1978).

3. MATERIALS AND METHODS

3.1. The study site

The experiment was conducted in Jimma zone, Nono Benja District Office of Agriculture, horticulture nursery site at Alga in the year 2013/2014 under irrigation. The site is located 156 km away from Jimma town and 252 km west of Addis Ababa city. The altitude of the site was 1670 m.a.s.l. The rainfall is unimodal and in the range of 780 – 1500 mm with about 70% of the precipitation falling in a two months' period, i.e., July and August. The annual minimum and maximum temperature is 14 and $26^{o}{}_{C}$ respectively. The soil was fine textured heavy loamy clay soil with a pH of 6.0 (JZOA, 2012).

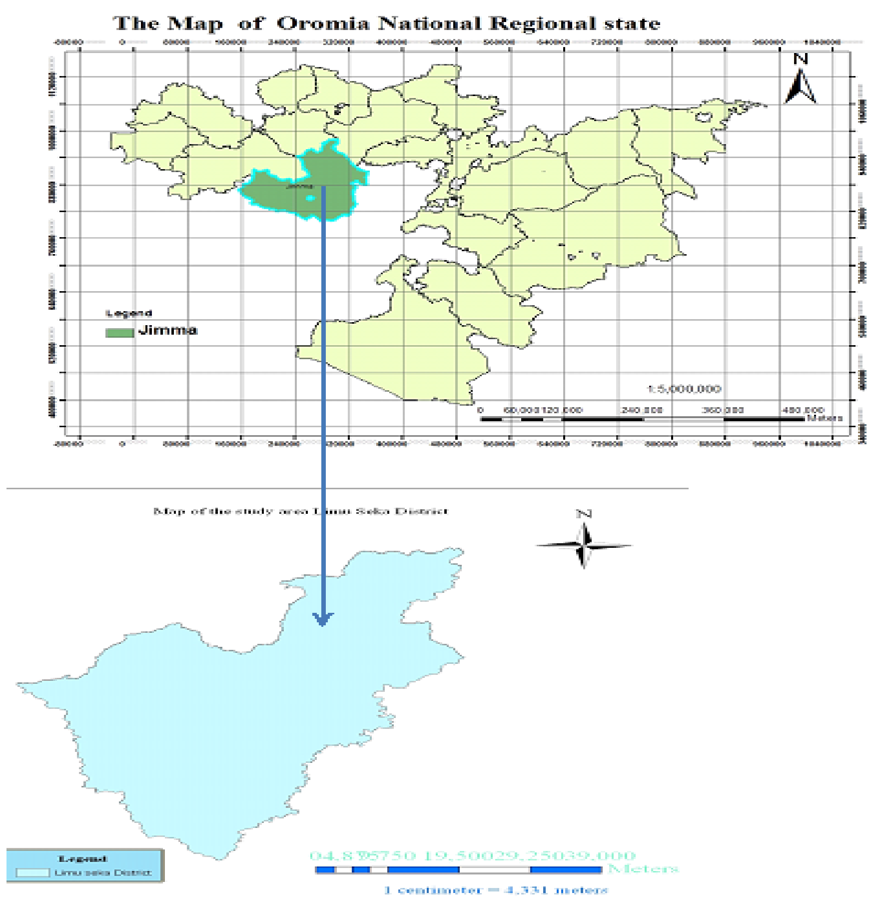

Figure 1: Map of the study site

3.2. Experimental materials

Two potato varieties (Jalenie and Gudenie) were used for this study (Table 1). The potato seed tubers were obtained from Holleta Agricultural Research Center. The varieties were selected due to their adaptability to the study area.

Table 1. Description of varieties *(Woldegiorgis et al., 2008).*

Name of varieties	Ecological requirement		Yield (t/ha)		Year of release	Breeder/ Center	Maturity days
	Altitude (m)	Rain fall (mm)	RM	FM			
Jalenie	1600-2800	750-1000	44.8	29.1	2002	HARC	90-120
Gudenie	1600-2800	750-1000	29.2	21	2006	HARC	120

RM= research field management, FM= farmers field management

3.3. Experimental treatments and design

The intra row spacing treatments of 20, 25, 30, 35 and 40 cm were used in this study. The seed tubers weighed and categorized under five weight ranges (20-35, 36-50, 51-65, 66-80 and 81-95 g) and used as seed tuber treatments.

The experiment was arranged in split - split plot design with three replications. The two varieties were assigned to the main plots, intra row spacing treatments to the subplots and tuber sizes were assigned to the sub-sub-plots.

3.4. Land preparation and management

The area of each and net total plot were 3 m x 3 m = 9 m^2, and 50 × 9 m^2 = 450 m^2 respectively with inter row spacing of 0.75 m throughout all experimental plots. The area for each main plot is 225 m^2 and each subplot is 45 m^2. Distance between blocks and plots are 50 cm and 20 cm respectively. As per the national recommendation 165 kg/ha UREA and 195 kg/ha Diammonium phosphate were applied. All other agronomic practices were applied as per crop production package.

3.5. Data collection

There are four rows of plants. Data are collected from two middle rows consisting of eight plants per row.

3.5.1. Crop phenology

1. **Days to 50% emergence.** Emergence data were taken at five days interval until three weeks after planting. It was recorded by counting the number of days from the planting date to the date at which about 50% of the plants in a plot is germinated. Final data used was that taken at 20^{th} date.

2. Days to 50% flowering. It was recorded by counting the number of days in which about 50% of plants flower from each plot.

3. Days to 50% physiological maturity. It was recorded when 50% of the plant populations have been shown yellowish or senescence of the haulms (vines).

3.5.2. Growth parameters

1. Number of main stem per plant. Data were recorded by counting those arising directly from the seed piece or tuber from each middle row during tuber initiation stage.

2. Plant heights (cm). Was measured from 16 plants of middle row from the base of main shoot to the apex when 50% of the stand was in bloom.

3.5.3. Yield parameters

1. Tuber number per plant. The tuber numbers per plant is a count of tubers from 16 plants of middle row plants was taken at harvest.

2. Average tuber weight (g). It was recorded by dividing total fresh weight of tubers per plot by the total number of tubers at harvest (Zelalem *et al*., 2009).

3. Marketable tuber yield (t/ha). At harvesting the middle row plants were collected from each plot for determination of marketable tuber yield. The estimation of marketable tuber yield from a plot was calculated on a hectare basis for weight of healthy tubers with a size of greater than 20 g was taken as marketable (Abbas *et al*., 2012).

4. Unmarketable tuber yield (t/ha). Rotten, diseased, insect damage, deformed tuber and tubers with weight of smaller than 20 g were considered as unmarketable tuber yield.

5. Total tuber yield (t/ha). It was recorded by adding both marketable and unmarketable tuber yields per plot and, then converted to hectare. This was taken at harvest.

3.5.4. Quality parameters

1. Tuber size categories. Tubers were collected, sorted by size, and counted from two central rows into three groups considering size of tubers as small (20-49 g), medium (50-75 g) and large (>75 g) (Mulubrhan, 2004).

2. **Tuber specific gravity (g/cm^3).** 5 kg of tubers were randomly taken per plot for estimation of tuber specific gravity. Tuber specific gravity was measured by using the tuber weight in air and in the water method. It was calculated using the formula described by Dinesh *et al.* (2005).

$$Tuber\ Specific\ Gravity\ (g/cm3) = \frac{Weight\ of\ tuber\ in\ air}{weight\ in\ air - weight\ in\ water}$$

3. Dry matter content (%). Tubers were randomly selected per plot and washed, chopped and mixed then about 200 g of sample was taken and pre-dry at a temperature of 60°C for 15 hrs and further dried for three hrs at 105°C in a drying oven. Finally, the amount was calculated by using the formula below.

$$Dry\ matter\ content\ (\%) = \frac{Dry\ weight}{Fresh\ weight} \text{x100}$$

3.6. Data analysis

The data were checked for all ANOVA assumptions. Analysis of variance (ANOVA) and correlation was done using SAS Version 9.2 statistical software (SAS Institute, 2008). Means separations were done using Tukey's test at 5% probability level. The following model for split-split plot design is used.

$$yijkl = \mu + Ri + Aj + Eij + Bk + (AB)jk + Eijk + Cl + (AC)jl + (BC)kl + (ABC)jkl + Eijkl$$

Where, μ = the overall mean effects
Ri = the effects of i^{th} replication, i = 1-3
Aj = the effects of the j^{th}variety, j = 1-2
Bk = the effects of the k^{th} intra row spacing, *k=1-5*
Cl= the effects of the l^{th} tuber size, *l=1-5*
Eij=the error term of variety
Eijk=the error term of the effects of variety and intra row spacing
Eijkl= the overall error of variety, intra row spacing and tuber size

i = 1, 2…, r
j = 1, 2…, a
k = 1, 2…, b
l = 1, 2…, c

4. RESULTS AND DISCUSSIONS

4.1. Crop phenology

4.1.1. Days to 50% emergence

The analysis of variance indicated that the two-way interaction of seed tuber size with intra row spacing and variety by tuber size were significantly ($P<0.05$) influenced the number of days to 50% emergence. However, no significant ($P<0.05$) interaction effect was observed between three way interaction on days to 50% emergence. The result revealed that treatment combinations of variety Jalenie with tuber size 81-95 g took significantly earlier days to 50% emergence (13.60). However, statistically the same days to 50% emergence (13.67) recorded from variety Jalenie using tuber size of 66-80 g. On the other hand, the treatment combinations form variety Gudenie with tuber size 36-50 g took longer days to 50% emergence (17.13) which was statistically similar results with (16.87) and (16.73) obtained with treatment combinations of variety Gudenie with tuber size 66-80 g and 81-95 g respectively (Table 2). Tuber size of 66-80 g planted at 40 cm intra row spacing numerically emerged earlier (14.17) as compared to others (Table 3). The earlier emergence of large seed tuber is an indication that large seed tuber had the advantage of having extra reserves, which promotes earlier emergence. The present result was in agreement with the finding of Mwansa (2002) who indicated earlier emergence of large seed tubers than the small seed tubers. On the other hand, the difference among varieties also observed indicating that the variety's genetic ability to develop sprouts to emerge earlier or later. This could be attributed to the genetic variation among different varieties used (Abubaker *et al.*, 2011). Addisu *et al.* (2013) also, indicated the existence of sufficient genetic variability among nine different potato varieties on days to 50% emergence and many other variables. Additionally, Helen *et al.* (2014) indicated the effect of variety at different location significantly influenced days to 50% emergence.

In addition to the variety effect, tuber size also influenced the days to 50% emergence. Days to 50% emergence was relatively increased as tuber size increase. The current result was associated with the fact that larger tuber seeds have superior capacity in providing higher contents of reserve materials facilitating earlier emergence and crop establishment and in the similar way as the intra row spacing increases the days to 50% emergence increases. The result of the present study was similar with the findings of Masarirambi *et al.* (2012) who reported larger tuber emerged earlier due to high content of stored food. Kumar *et al*. (2009) also reported large seed tuber showed higher emergence compared to smaller seed in their study. The earlier plant emergence was recorded from large seed tubers (51-70 g) compared to smaller seed tubers which may be resulted in better plant growth (Patel *et al.*, 2008).

Table 2. Interaction effect of variety and tuber size on days to 50% emergence of potato in 2013/2014 at Nono Benja.

Tuber size (g)	Variety	
	Jalenie	Gudenie
20-35	14.47^{c}	16.67^{b}
36-50	14.27^{dc}	17.13^{a}
51-65	14.27^{dc}	16.27^{b}
66-80	13.67^{de}	16.87^{ab}
81-95	13.60^{e}	16.73^{ab}
SEM	0.23	
CV (%)	5.9	
LSD (5%)	0.65	

Means with the same letter (s) within columns and rows of a variable were not significantly different at P < 0.05. SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

Table 3. Interaction effect of intra row spacing and tuber size on days to 50% emergence of potato in 2013/2014 at Nono Benja.

Intra row spacing (cm)	Tuber size (g)				
	20-35	36-50	51-65	66-80	81-95
20	16.67^{a}	15.67^{abcd}	15.67^{abcd}	15.17^{cde}	15.33^{cde}
25	16.50^{ab}	15.50^{bcd}	15.67^{abcd}	15.17^{cde}	15.33^{cde}
30	15.67^{abcd}	15.50^{bcd}	15.33^{cde}	14.83^{de}	15.17^{cde}
35	16.00^{abc}	15.33^{cde}	15.17^{cde}	14.83^{de}	15.17^{cde}
40	16.00^{abc}	15.00^{cde}	15.00^{cde}	14.17^{e}	15.00^{cde}
SEM			0.37		
CV (%)			5.4		
LSD (5%)			1.03		

Means with the same letter (s) within a columns and rows of a variable were not significantly different at P < 0.05. SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

4.1.2. Days to 50% flowering

Analysis of variance indicated that there was a significant (P<0.05) interaction effect between variety and intra row spacing on days to 50% flowering (Table 4; Appendix Table 1). The three ways interaction tuber size was non-significant (Appendix Table 1). The earliest (53.33) days to

50% flowering was recorded from variety Jalenie planted at intra row spacing of 20 cm followed by variety Jalenie planted at 25 cm (55.13), whereas, the prolonged (72.60) days to 50% flowering was recorded from variety Gudenie planted at intra row spacing 40 cm (Table 4). As intra row spacing increase, days to 50% flowering got delayed all over treatment combinations for both varieties. This could be due to higher competition of plants for resources in the closer intra row spacing that lead the plants to stress and ultimately the plants flower early instead of prolonged vegetative growth (Tesfaye *et al.,* 2012). The varietal differences can also influenced days to 50% flowering as indicated by Helen *et al.* (2014). The difference in days to 50% flowering is due to genetic variability among different varieties of potato (Addisu *et al.,* 2013).

Table 4. Interaction effect of variety and intra row spacing on days to 50% flowering of potato in 2013/2014 at Nono Benja.

Intra row spacing (cm)	Variety	
	Jalenie	Gudenie
20	53.33^{h}	67.60^{d}
25	55.13^{g}	68.33^{dc}
30	56.33^{f}	69.20^{c}
35	57.27^{ef}	70.73^{b}
40	57.48^{e}	72.60^{a}
SEM	0.35	
CV (%)	2.01	
LSD (5%)	0.99	

Means with the same letter (s) with in a column of a variable were not significantly different at (P<0.05). SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

4.1.3. Days to 50% physiological maturity (DPhM)

The analysis indicated that days to 50% physiological maturity was only significantly (P<0.05) affected by variety. In Nono Benja area, the maturation period for potato varied from 85 to 115 depending on varieties (Figure 2). The longest days to maturity was recorded for variety Gudenie while variety Jalenie was early in maturity. Tibebu *et al.* (2014) also reported that tuber size as well as interaction effects of variety by tuber size do not influenced days to 50% physiological maturity. According to Harnet *et al.* (2014) days to 50% physiological maturity was significantly influenced by varieties. In contrary to the present study, Tesfaye *et al.* (2012) reported that the earliest days to 50% physiological maturity as it influenced by intra row spacing.

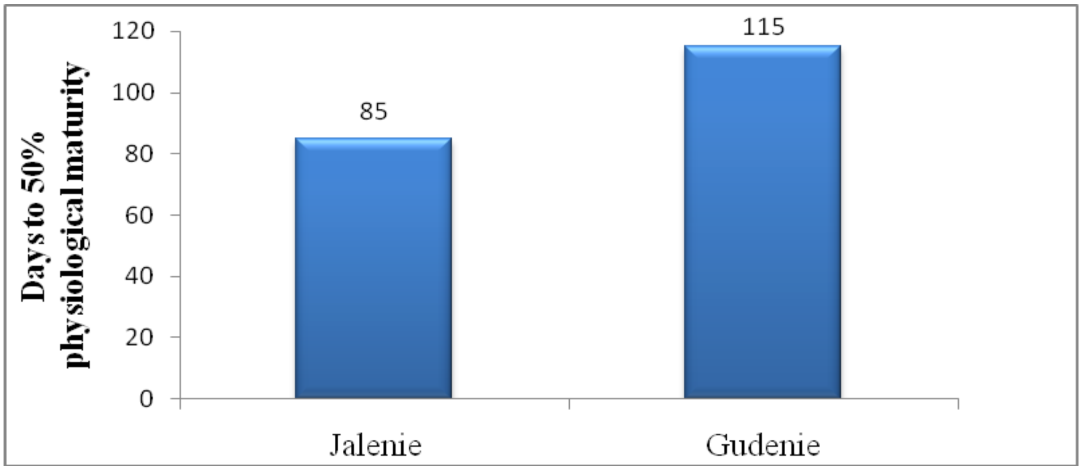

Figure 1: Days to 50% physiological maturity for potato varieties

4.2. Growth parameters

4.2.1. Plant height

The three way interaction of variety, intra row spacing and tuber size were significantly (P<0.05) influenced plant height (Table 5; Appendix Table 1). The highest plant height (80.38 and 79.75 cm) was recorded from variety Gudenie with tuber size of 66-80 g and 81-95 g planted at intra row spacing of 35 cm and 25 cm respectively. Statistically similar result (79.09 cm) was recorded from variety Gudenie with tuber size 66-80 g planted at 30 cm intra row spacing, while the shortest plant height (46.54 cm) was recorded from variety Jalenie with tuber size 35-50 g planted at 35 cm (Table 5). The plant height from treatment combinations of variety Gudenie was higher by 6.30 cm than treatment combinations of variety Jalenie (Table 5). The highest plant height was recorded for variety Gudenie at widest intra row spacing indicating differential varietal responses in line with Helen *et al*. (2014) who confirmed the differences in plant heights of the varieties might be attributed to genetic differences, which might have led to the variable performances in growth and development. Plant height increased progressively with increase in intra row spacing depending on variety (Mangani *et al.*, 2015). Densely populated plants (closer inter and intra row spacing) show intensive competition which leads to decrease in plant heights (Bikila *et al.*, 2014). In contrary to the present study, Tesfaye *et al.* (2012) indicated the highest plant height from closer intra row spacing of 10 and 20 cm. Closer intra rows spacing increased plant height at the temperate climate zone, but decreased it at the tropical climate (Zaag *et al.*, 1990).

On the other hand, the present result indicates the combination of large seed tuber size gave highest plant height, which was in line with the findings of Islam *et al.* (2012) who reported the large seed tuber sizes have more food reserve to supply sufficient nutrient to plant and enhance plant height.

4.2.2. Number of main stem per plant

The analysis of variance indicated that the three way interaction of variety, intra row spacing and tuber size was found significant ($P<0.05$) on number of main stems per plant. Numerically the highest (9.79) number of main stem was recorded from variety Jalenie with tuber size of 81-95 g planted at intra row spacing of 40 cm followed by (9.60) obtained from variety Jalenie with tuber sizes of 66-80 g planted at intra row spacing of 40 cm (Table 5). The lowest (2.17) number of main stems per plant was obtained from variety Gudenie with tuber size 20-35 g planted at intra row spacing of 35 cm and this was statistically not significant with number of main stems produced by variety Jalenie with tuber size of 20 -35 g planted at 20 and 25 cm (Table 5). As indicated from the result the combinations of wider intra row spacing and larger seed tuber sizes produced higher number of main stems. Production of higher number of main stem per plant by treatment combinations from variety Jalenie was probably due to its genetic potential for sprouting capacity (Bewuketu, 2012). Seed factors such as seed size is by far the most influential as they govern the number of main stems that can emanate from a seed tuber size (Shayanowako *et al.,* 2014). Seed size also influence the number of sprouts and thus the number of main stems produced per seed tuber, and with the same seed size treatments tubers of different varieties will produce a different number of main stems per plant (Hue, 2008).

The variations in tuber size among treatments in this study might be contributed to the variations in number of main stem per plant in agreement with Helen *et al.* (2014) who indicated the difference between varieties in number of main stem could be variations in the number of buds per tubers, which was then influenced by the tuber size. Masarirambi *et al.* (2012) conducted on four levels of seed tuber size and plant population, and reported significant differences in number of main stem per plant across four seed sizes. It found that the number of main stems produced per tuber increased with increasing tuber size and intra row spacing (Rajadurai, 1994).

Table 5: Interaction effects of variety, intra row spacing and tuber size on growth parameters of potato in 2013/2014 at Nono Benja.

Treatments			Growth parameters	
Variety	Intra row spacing (cm)	Tuber size (g)	Number of main stems	Plant height (cm)
Jalenie	20	20-35	2.21^{uv}	47.71^{t}
		36-50	2.69^{st}	47.43^{t}
		51-65	4.84^{mn}	48.90^{t}
		66-80	6.02^{ghij}	57.04^{p-s}
		81-95	6.40^{g}	63.79^{jkl}
	25	20-35	2.31^{tuv}	65.35^{g-k}
		36-50	3.33^{pq}	54.02^{n-s}
		51-65	4.79^{mn}	58.48^{n-q}
		66-80	8.38^{c}	74.08^{bc}
		81-95	8.19^{c}	63.44^{jkl}
	30	20-35	2.73^{rst}	48.06^{t}
		36-50	3.29^{q}	48.96^{t}
		51-65	5.08^{lm}	61.81^{k-n}
		66-80	7.52^{ef}	70.48^{b-f}
		81-95	8.09^{cd}	65.08^{h-l}
	35	20-35	3.23^{q}	54.63^{qrs}
		36-50	3.52^{pq}	46.54^{t}
		51-65	5.46^{kl}	57.75^{o-r}
		66-80	8.35^{c}	65.04^{h-l}
		81-95	9.10^{b}	58.40^{n-q}
	40	20-35	3.25^{q}	46.67^{t}
		36-50	4.11^{o}	48.21^{t}
		51-65	6.19^{gh}	56.31^{p-s}
		66-80	9.60^{a}	65.02^{h-l}
		81-95	9.79^{a}	56.94^{p-s}
Gudenie	20	20-35	2.27^{tuv}	56.73^{p-s}
		36-50	3.33^{pq}	64.27^{h-l}
		51-65	3.42^{pq}	67.33^{e-j}
		66-80	5.00^{lmn}	74.40^{b}
		81-95	4.60^{n}	71.83^{bcd}
	25	20-35	2.27^{tuv}	59.02^{m-p}
		36-50	3.50^{pq}	64.65^{h-l}
		51-65	3.79^{op}	64.13^{i-l}
		66-80	6.17^{ghi}	71.21^{b-e}
		81-95	5.69^{jk}	79.75^{a}
	30	20-35	2.64^{stu}	53.56^{s}
		36-50	3.29^{q}	69.25^{d-g}
		51-65	5.65^{jk}	68.23^{d-h}
		66-80	7.40^{ef}	79.09^{a}

		81-95	6.10^{ghij}	70.44^{b-f}
	35	20-35	2.17^{v}	66.69^{fg}
		36-50	3.17^{qr}	65.21^{h-k}
		51-65	5.44^{kl}	67.98^{d-i}
		66-80	7.15^{f}	80.38^{a}
		81-95	5.75^{hijk}	69.30^{d-g}
	40	20-35	2.42^{tuv}	62.54^{klm}
		36-50	3.11^{qrs}	61.17^{l-o}
		51-65	5.71^{ijk}	62.63^{klm}
		66-80	7.67^{de}	70.31^{c-f}
		81-95	6.06^{ghij}	70.19^{c-f}
SEM			0.17	1.47
CV (%)			5.95	4.17
LSD (5%)			0.47	4.13

Means with the same letter (s) within a column of a variable were not significantly different at (P < 0.05). SEM = Standard error mean, CV = Coefficient of variation and LSD = Least significance difference.

4.3. Yield parameters

4.3.1. Tuber number per plant

There was significant (P<0.05) three way interaction effect of variety, intra row spacing and tuber size on tuber number per plant (Table 6; Appendix Table 2). Numerically, the highest (8.63) tuber number per plant was recorded from variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 25 cm followed by variety Jalenie with tuber size of 81-95 g planted at intra row spacing of 20 cm (8.32) (Table 6).The lowest tuber number (4.37) was obtained from variety Gudenie with tuber size of 20-35 g planted at intra row spacing of 20 cm (Table 6). Treatment combinations from both varieties gave different results of tuber number per plant. This is due to the varietal differences in bulking of tubers. On the other hand, large tubers gave higher number of tuber while smaller tuber gave lower. This might be indicated the fact that large tuber had the potentials to have high number of sprouts which produces more number of tuber per plant. Large tubers (66-95 g)combined with narrow intra row spacing (25 cm) produced 8.63 tubers per plant due to more plant populations per unit area and high bulking ability of large seed tubers to bear more numbers of tubers than small seed tubers. In addition to this, the highest numbers of tubers at closer intra row spacing is due to high number of plants per unit area in line with the finding of Harnet *et al.* (2014). The present finding was similar with the work of Rajadurai (1994), who reported the combination of large size seed tubers and narrow intra row spacing produced many small size tubers of low market value. Large seed tubers produced more number of tubers per plant significantly over small seed tubers (Islam *et al.*, 2012). Roy *et al.* (2015) reported the highest tuber numbers per plant from25 cm intra row spacing while the lowest value from 15 cm intra row spacing. In contrary to the present study the same authors reported the highest tuber numbers per plant from tuber size of 30-40 g followed by tuber size 40-50 g. Tuber number per plant and per hectare consistently increased with increasing seed tuber size, which was similar with findings of Gulluoglu and Arioglu (2009). More tuber numbers per plant were obtained from large seed tuber sizes and consequently, the bulking period was greater in large seed tuber size across all plant densities (Masarirambi *et al.*, 2012). Tibebu *et al.* (2014) conducted study on tuber sizes and indicated that variety Jalenie scored the highest while variety Gudenie scored the lowest tuber number per plant, which might be because of variety difference.

4.3.2. Average tuber weight

The analysis of variance result indicated that the three way interaction of variety, intra row spacing and tuber size was significantly ($P<0.05$) influenced average tuber weight (Table 6; Appendix Table 2). The twoway interactions of variety by intra row spacing, variety by tuber size and intra row spacing by tuber size were also significant (Appendix Table 2). The highest average tuber weight (66.05 g) was recorded from variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 30 cm,while the lowest average tuber weight (43.67 g)was recorded from variety Gudenie with tuber size of 20-35 g and planted at intra row spacing of 20 cm(Table 6). The present study showed the fact that an increase in intra row spacing and tuber size result in an increase in average tuber weight of potato.This is due to the reason that large seed tuber size which can provide sufficiently the required substances for growth and development at initial growth phase. Decrease in intra row spacing probably increased competition between plants, hence, leads to decrease in availability of nutrients to each plant, and consequently, resulted in decline of mean tuber weight. The wider intra row spacing permits freely growth without any competitions for minerals and other requirements. On the other hand, there might be differences in variety to produce different sizes of tubers. In this case, genetically the performances of varieties in producing more amounts of large or small tubers might be different.

Total and marketable tuber yield might be related to the average tuber weight and the uniformity of seed piece weight within a seed lot (Nielson *et al.*, 1989). The high average tuber weight for treatment combination of Jalenie was due to the naturally containing high number of buds (eye) (Bewuketu, 2012). The increase plant population probably increased competition between and within plants and hence, led to decrease in availability of nutrients to each plant and, consequently, resulted in decline of average tuber weight (Harnet *et al.*, 2014). Closer intra row spacing and large seed tubers gave less tuber weight (Khalafalla, 2001). Average tuber weight values tended to increase with increasing intra row spacing (Gulluoglu and Arioglu, 2009).

Table 6: Interaction effects of variety, intra row spacing and tuber size on yield parameters of potato in 2013/2014 at Nono Benja.

Treatments			Yield parameters				
Variety	Intra row Spacing (cm)	Tuber size (g)	MTY (t/ha)	UMTY (t/ha)	TTY (t/ha)	TN	ATW (g)
		20-35	11.64^{i-l}	5.01^{ghi}	16.65^{l-r}	6.46^{i-q}	47.51^{vwx}
	20	36-50	16.55^{b-f}	7.24^{abc}	23.80^{abc}	6.31^{k-r}	49.45^{r-u}
		51-65	16.58^{b-f}	7.46^{ab}	24.05^{abc}	6.67^{g-o}	51.90^{mno}
		66-80	17.04^{a-d}	6.49^{cd}	23.52^{a-d}	7.64^{b-f}	56.72^{efg}
		81-95	16.76^{b-f}	7.52^{a}	24.38^{ab}	8.32^{ab}	56.03^{f-i}
		20-35	14.66^{c-h}	6.43^{cde}	21.09^{a-j}	7.38^{c-h}	55.20^{g-k}
	25	36-50	15.14^{c-g}	6.29^{cdef}	23.40^{a-d}	7.18^{e-k}	56.59^{fgh}
		51-65	17.12^{a-f}	4.76^{f-l}	19.91^{d-m}	6.63^{g-o}	55.74^{g-j}
		66-80	19.93^{a}	4.91^{f-k}	24.84^{a}	8.63^{a}	53.69^{klm}
Jalenie		81-95	19.48^{ab}	5.06^{ghi}	24.54^{ab}	8.21^{abc}	50.82^{o-s}
		20-35	13.77^{c-j}	3.49^{m-s}	18.08^{h-q}	6.91^{e-m}	51.13^{o-r}
	30	36-50	14.59^{c-i}	4.63^{h-m}	19.22^{e-o}	7.35^{c-i}	56.80^{efg}
		51-65	15.83^{c-f}	3.56^{m-s}	19.39^{e-n}	6.83^{f-n}	57.76^{def}
		66-80	17.00^{a-f}	2.22^{uv}	19.22^{e-o}	7.53^{b-g}	66.05^{a}
		81-95	19.57^{ab}	2.15^{v}	21.82^{a-h}	7.16^{e-k}	54.22^{jkl}
		20-35	13.39^{d-j}	3.51^{m-s}	16.90^{l-r}	6.30^{k-r}	52.13^{m-o}
	35	36-50	17.41^{a-f}	3.63^{m-s}	21.95^{a-g}	6.95^{e-l}	53.03^{l-o}
		51-65	18.32^{a-d}	2.88^{q-v}	20.28^{c-l}	7.38^{c-h}	54.59^{i-l}
		66-80	19.43^{ab}	4.22^{i-o}	24.15^{ab}	7.80^{a-e}	56.17^{f-i}
		81-95	14.88^{c-h}	2.82^{r-v}	17.69^{i-r}	7.24^{d-j}	58.99^{d}
		20-35	13.08^{e-k}	4.44^{h-n}	22.35^{a-f}	5.87^{o-t}	48.76^{tuv}
	40	36-50	13.50^{c-j}	2.46^{h-m}	15.54^{o-r}	6.30^{k-r}	49.92^{p-t}
		51-65	13.74^{c-j}	2.70^{s-v}	16.19^{m-r}	6.24^{k-r}	50.15^{p-t}
		66-80	17.91^{a-e}	3.97^{k-p}	22.55^{a-e}	8.23^{abc}	50. 74^{o-s}
		81-95	18.58^{abc}	2.82^{r-v}	21.40^{a-i}	6.81^{f-n}	51.24^{opq}
Gudenie		20-35	8.58^{l}	5.60^{c-g}	14.18^{r}	4.37^{v}	43.67^{z}
	20	36-50	12.39^{f-k}	5.42^{fgh}	17.81^{i-r}	6.17^{l-r}	43.73^{z}
		51-65	12.88^{e-k}	5.19^{gh}	18.07^{h-q}	5.84^{o-t}	43.75^{z}
		66-80	12.17^{f-k}	4.38^{h-n}	16.55^{l-r}	6.43^{j-q}	43.81^{z}
		81-95	10.98^{i-l}	4.33^{h-o}	15.31^{pqr}	6.00^{m-s}	44.77^{yz}
		20-35	10.23^{kl}	4.97^{f-j}	15.20^{pqr}	5.43^{r-u}	43.73^{z}

	36-50	11.68^{h-l}	4.38^{h-n}	16.06^{n-r}	5.18^{s-v}	43.71^{z}
25	51-65	12.00^{f-k}	5.41^{efg}	17.41^{j-r}	6.48^{h-q}	43.52^{z}
	66-80	14.63^{c-h}	4.18^{i-o}	18.81^{e-p}	8.16^{a-d}	43.71^{z}
	81-95	16.44^{b-f}	4.36^{h-n}	20.80^{n-s}	5.71^{p-u}	44.58^{yz}
	20-35	11.10^{i-l}	4.41^{h-n}	15.51^{o-r}	6.14^{l-r}	47.73^{uvw}
	36-50	12.41^{f-k}	4.24^{h-o}	16.65^{l-r}	7.17^{e-k}	50.85^{o-s}
30	51-65	15.08^{c-g}	3.56^{m-s}	18.64^{f-q}	7.76^{a-e}	52.00^{mno}
	66-80	15.13^{c-g}	2.86^{q-v}	17.99^{i-q}	6.63^{g-o}	54.92^{h-k}
	81-95	12.88^{e-k}	3.81^{k-q}	16.69^{l-r}	6.61^{h-p}	62.94^{b}
	20-35	11.81^{h-k}	4.61^{h-m}	16.42^{m-r}	5.86^{o-t}	45.90^{xy}
	36-50	12.12^{f-k}	4.01^{j-p}	16.14^{m-r}	5.68^{q-u}	49.15^{s-v}
35	51-65	12.30^{f-k}	3.76^{m-r}	16.06^{n-r}	5.23^{s-v}	49.52^{q-t}
	66-80	14.79^{c-h}	3.55^{m-s}	18.34^{g-q}	7.60^{b-f}	58.46^{de}
	81-95	11.78^{h-l}	3.15^{p-u}	14.92^{qr}	5.77^{o-t}	60.83^{c}
	20-35	12.23^{f-k}	3.64^{m-s}	15.87^{n-r}	4.83^{uv}	46.71^{wx}
	36-50	12.39^{f-k}	3.51^{m-s}	15.90^{n-r}	5.03^{tuv}	49.61^{q-t}
40	51-65	13.76^{c-j}	3.39^{o-u}	17.15^{k-r}	6.00^{n-s}	51.42^{nop}
	66-80	15.72^{c-f}	2.73^{s-v}	18.49^{g-q}	6.49^{h-q}	51.61^{mnop}
	81-95	14.70^{c-h}	3.47^{n-s}	18.17^{h-q}	6.50^{h-q}	52.19^{mno}
SEM		1.12	0.34	1.35	0.33	0.63
CV (%)		13.2	13.7	12.2	8.5	2.1
LSD (5%)		3.15	0.96	3.78	0.91	1.77

Means with the same letter (s) with in a column of a variable were not significantly different at P < 0.05. MTY=Marketable tuber yield, UMTY=Unmarketable tuber yield, TTY=Total tuber yield, TN =Tuber number per plant, ATW=Average tuber weight, SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

4.3.3. Marketable tuber yield

The three way interaction of variety, intra row spacing and tuber size significantly (P<0.05) influenced marketable tuber yield (Table 6; Appendix Table 2). The two way interactions of variety by intra row spacing, variety by tuber size and intra row spacing by tuber size were also significant (Appendix Table 2). Numerically the highest (19.93 t/ha) marketable tuber yield was obtained from variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 25 cm. This is statistically at par with variety Jalenie with tuber size of 81-95 g and 66-80 g and planted at intra row spacing of 30 and 35 cm (19.57 t/ha and 19.43 t/ha), respectively. The lowest marketable tuber yield (8.58 t/ha) was obtained from variety Gudenie with tuber size of 20-35 g planted at intra row spacing of 20 cm (Table 6). The present study indicates that the larger seed tuber sizes produces high marketable tuber yields. Large seed tubers combined with all intra row spacing produces statistically similar marketable tuber yields. This is due to the fact that large seed tubers can withstand even the effects of population because of the high performances to provide stored food at early growth phase, which supports in producing high marketable tuber yield. The present result is in agreement with the finding of Harnet *et al.* (2014), who reported large seed tuber had more food reserve to supply sufficient nutrient to plant and enhance production of marketable tuber yield. Mangani *et al.* (2014) also reported that plants were able to efficiently use the available growth requirements and had a direct effect on yield. The difference among varieties also observed clearly in which variety Jalenie resulted in higher production of marketable tuber yield than variety Gudenie. In contrary to the present result, Roy *et al.* (2015) indicated high marketable tuber yield from small seed tubers of 30-40 g. The present result was also similar with the finding of Ayupov *et al.* (2014) who reported in case of increasing plant density, the marketability of the tubers declines.

4.3.4. Unmarketable tuber yield

The analysis of variance indicated that unmarketable tuber yield was significantly ($P<0.05$) affected by the three way interaction of variety, intra row spacing and tuber size (Table 6; Appendix Table 2). The two way interactions of variety by intra row spacing, variety by tuber size and intra row spacing by tuber sizewere also significantly ($P>0.05$) influenced unmarketable tuber yield (Appendix Table 2). The highest unmarketable tuber yield (7.52 t/ha)was recorded from variety Jalenie with tuber size of 81-95 g planted at intra row spacing of 20 cm followed by (7.46 t/ha) and (7.24 t/ha) by variety Jalenie with tuber sizes of 51-65 g and 36-50 g planted at intra row spacing of 20 cm. The smallest (2.15 t/ha) unmarketable tuber yield was obtained from variety Jalenie with tuber size of 81-95 g planted at intra row spacing of 30 cm (Table 6).

Unmarketable tuber yield was produced from small seed tubers. This might be due to the low content of stored foods in small size seed tubers, which intern failure in supporting the plant growth. The smaller the seed tuber the same size tuber yield can expected since the production of tuber yield were depends on the performances of seed tubers at planting. In the present study, large seed tubers planted at narrow intra row spacing resulted in the production of relatively higher unmarketable tuber yield. This is actually describe the fact that large seed tubers when planted at narrow intra row spacing produces high yield of small tubers. This is due to the high potential of sprouting and bears many stems by large seed tubers to support the whole growth and development of plant and the tubers became smaller because of plant competition. Therefore, the present study was similar with the work of Tesfaye *et al.* (2012) who reported that as decrease intra row spacing the production of unmarketable tuber yield increased. Additionally, Gulluoglu and Arioglu (2009) reported that planting of large seed tubers at closer intra row spacing resulted in lower tuber yield because of high production of smaller and unmarketable tuber yield due to increasing intra plant competition.

In all cases as increment of intra row spacing, there was a decrease in the production of unmarketable tuber yield, which was in line with the findings of Ayupov *et al.* (2014) who indicated with an increasing of intra row spacing, the production of unmarketable tuber yield declines. This might be caused by the fact that the competitions of plants with each other for growth factors or resources were increase with increment of plant populations (Wiersema, 1987). It is interesting to note that the smaller size seed tubers when used for planting produced more number of smaller tubers, which become unmarketable tubers (Kumar *et al.*, 2009).

4.3.5. Total tuber yield

The analysis of variance indicated that the three way ($P<0.05$) interaction had significant effect (variety, intra row spacing and tuber size) on total tuber yield (Table 6; Appendix Table 2). Numerically, the highest total tuber yield (24.84 t/ha)was recorded from variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 25 cm followed by variety Jalenie with tuber size of 81-95 g planted at intra row spacing of 25 and 20 cm respectively. The lowest total tuber yield(13.97 t/ha) was obtained from variety Gudenie with tuber size of 66-80 g planted at intra row spacing of 30 cm (Table 6).

The total tuber yield in the present study indicates that at high plant population there was high production of total tuber yield (Table 6). This shows that at higher plant population there might be a production of high number of tubers per plant, which results in high tuber yield. When there was a high completion due to plant population, many small size tubers produced per unit area. On the other hand, the production of total tuber yield in the present study indicated also the varietal differences. Hence, the ability to produce tubers depends on the potentials of each variety to bear sprout and stems. Tibebu *et al.* (2014) also reported similar results that total potato tuber yield of variety Jalenie was significantly higher than variety Gudenie. In contrary to the present study, maximum total tuber yield observed in variety Gudanie than variety Jalenie (Addisu *et al.*, 2013). Patel *et al.* (2008) conducted study on seed tuber sizes and indicated that the larger size tubers of 51-70 g resulted in higher tuber yield, which might be due to rapid seedling emergence and better plant growth. They also indicated that larger tuber sizes produced higher yields of seed size tubers because of higher number of tubers per plant in larger tuber size as well as combined effect of all other growth and yield attributes. The yield increase could be attributed primarily to increased weight of seed tubers (Mahmoudpour, 2014).

The result of present study was also similar with the findings of Masarirambi *et al.* (2012) who indicated that reducing the intra-row spacing from 45 to 30 cm significantly increased plant population and subsequently increased the total tuber yield. The total tuber yield that was important but proportion of different tuber size has great significance (Kumar *et al.*, 2009). In contrary to the present study, Roy *et al.* (2015) reported that the highest total tuber yield was observed in the intra row spacing of 20 cm.

4.4. Quality parameters

4.4.1. Fresh tuber size categories

4.4.1.1. Large tuber (>75 g)

The three ways interaction was significantly affected mean yield of large tuber size (>75 g) (Table 7; Appendix Table 3). The two ways interactions of variety by intra row spacing, variety by tuber size and intra row spacing by tuber size were also significant (Table 7; Appendix Table 3). The highest (10.18 t/ha) mean yield of large tuber was recorded from variety Gudenie with tuber size of 66-80 g planted at 25 cm followed by variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 30 cm (10.14 t/ha) (Table 7). The least (4.77 t/ha) mean yield of large tubers was recorded from variety Jalenie with tuber size of 20-35 g planted at intra row spacing of 20 cm (Table 7). The result indicated the small seed tuber planted at closer intra row spacing produced lower mean yield of large tubers than large seed tuber planted at wider intra row spacing from both varieties. Large tuber yield obtained from the large seed tuber in this study indicated that the large seed tubers had the potentials to produce large tuber yield due to its high content of carbohydrate to feed plant. The emerged plants from large seed tubers can sufficiently compete for resources with other neighboring plant. On the other hand, small seed tubers as discussed in the previous portions had no ability of equal competition with other plant for resources and had also little amount of carbohydrate source to support plant at earlier growth period. The variety might be observed difference in production large tubers. Variety Gudenie produced high mean yield of large tubers while variety Jalenie was less in mean yield of large tuber in line with the finding of Helen *et al.* (2014) who reported the genetic ability of varieties to sprout and produce tubers. In similar way plant population affects the production of large tubers as observed in this study. In this case, the increment of intra row spacing from 30 to 40 cm might decrease mean yield of large tubers, but intra row spacing ranges from 20 to 30 cm the yield shown relatively increasing. The large tuber production indicated at intra row spacing of 30 to 40 cm was because of the less competition between plants and the tuber became large enough and less in tuber number per plant. The present study might be concluded as the larger seed tuber size and the wider intra row spacing used in ware potato production the higher larger tubers obtained. This could be indicated that larger seed tubers can provide ample amounts of required stored food and necessary substrates for performance of tuber yield. Wider intra row spacing also provide sufficient air movement and circulation in between the plants and this could be used in getting equal sun light for photosynthesis activities, which results in productivity of large tubers less in number.

The difference in intra row spacing shows that both varieties are different in their canopy growth. The present result was indicated the fact that potato growth as well as variety development and performance might be the causes for variation in tuber size among different varieties in line with the work of Levy (2007). Gulluoglu and Arioglu (2009) indicated also that the tuber size was significantly affected yield of large tubers, and the ratio of large tubers which significantly affected by in-row spacing treatments. Large seed tubers also produced more number of large size tubers and tuber yield per plant (Sultana *et al.*, 2001; Kumar *et al.*, 2009). Rajadurai (1994) reported the combination of large seed tubers and intra row spacing of 20 cm produced many small size tubers, i.e., decreased in large tubers. Love and Thompson-Johns (1999) reported also that as the spacing widened, the tubers became larger in size and less in number.

4.4.1.2. Medium tuber (50 - 75 g)

The three ways interaction of variety, intra row spacing and tuber size had significantly affected mean yield of medium tuber sized (Table 7; Appendix Table 3). The two way interactions were also significant (Appendix Table 3). Numerically, variety Jalenie with tuber size of 66-80 g planted at 25 cm produced the highest (8.04 t/ha) mean yield of medium sized tubers followed by variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 40 cm (7.58 t/ha) (Table 7). The result indicated that variety Jalenie produced relatively higher mean yield of medium sized tubers. Through all seed tubers used in this study variety Gudenie produced lower mean yield of medium size tubers.

Therefore, this is actually recognized the fact that there were genetically differences among varieties in production of medium size tubers as well. As indicated by Helen *et al.* (2014) there were differences in yields of medium tuber size for different varieties. Love and Thompson-Johns (1999) indicated that the highest medium size tuber yield did not occur at the same spacing for both varieties under study. Average tuber size decreased with increasing stem or tuber density (Bussan *et al.,* 2007).

4.4.1.3. Small tuber size (20 - 49 g)

The three ways interaction of variety, intra row spacing and tuber size had significantly affected small tuber size (Table 7; Appendix Table 3). The two way interactions were also significant (Appendix Table 3). The highest mean yield of small tuber (8.59 t/ha) was recorded from variety Jalenie with larger tuber size 81-95 g planted at intra row spacing of 20 cm (Table 7). The result clearly indicates that the production of small sized tubers depends on variety, through variety Jalenie relatively higher mean yield of small sized tubers, but from variety Gudenie almost similar values were observed through all seed tuber sizes and intra row spacing. Therefore, Varietal differences can play a vital role in enhancing the production of small sized potato tubers as indicated by the present study. The result confirmed the findings of Akbari *et al.* (2013) who indicated different smaller tuber yield with different varieties might be different. Similar result observed among treatments from variety Gudenie was the same with the finding of Mangani *et al.* (2015) who reported through narrow and wider intra row spacing the production of small sized tubers was the same. Mean yield of small tubers of potato was significantly differed depending on variety (Abbasi *et al.,* 2004).

Table 7. Interaction effects variety, intra-row spacing and tuber size on quality related parameters of potato in 2013/2014 at Nono Benja.

Treatments			Quality parameters		
Variety	Intra row Spacing (cm)	Tuber size (g)	LT (t/ha)	MT (t/ha)	ST (t/ha)
		20-35	4.77^{q}	3.06^{n-u}	3.82^{h-k}
		36-50	6.48^{g-o}	5.07^{g-k}	5.00^{c-f}
	20	51-65	6.40^{h-p}	5.22^{e-j}	4.96^{c-g}
		66-80	6.25^{h-p}	6.20^{b-h}	4.58^{d-i}
		81-95	7.32^{e-j}	4.24^{j-o}	8.59^{a}
		20-35	6.16^{i-q}	3.33^{n-t}	5.16^{b-e}
		36-50	6.40^{h-p}	5.80^{d-i}	4.91^{c-g}
	25	51-65	6.06^{j-q}	6.97^{a-d}	5.42^{bcd}
		66-80	7.04^{f-m}	8.04^{a}	4.83^{c-g}
Jalenie		81-95	7.35^{e-j}	6.25^{b-g}	5.88^{b}

		20-35	5.56^{m-q}	4.82^{g-m}	4.21^{f-j}
	30	36-50	5.68^{k-q}	6.62^{a-e}	4.41^{e-j}
		51-65	5.97^{j-q}	6.66^{a-d}	5.61^{bc}
		66-80	10.14^{a}	6.03^{c-h}	4.12^{g-j}
		81-95	5.13^{opq}	4.95^{g-l}	3.69^{jk}
		20-35	5.41^{n-q}	3.70^{k-q}	4.28^{f-j}
		36-50	6.40^{h-p}	7.24^{abc}	4.68^{d-h}
	35	51-65	6.25^{h-p}	6.52^{b-f}	4.64^{d-h}
		66-80	7.42^{e-j}	6.90^{a-d}	5.61^{bc}
		81-95	5.59^{l-q}	5.15^{f-j}	4.12^{g-j}
		20-35	6.24^{h-q}	7.04^{a-d}	4.62^{bc}
		36-50	4.96^{pq}	4.41^{i-n}	3.71^{ijk}
	40	51-65	5.03^{opq}	4.78^{h-m}	3.69^{jk}
		66-80	6.34^{h-p}	7.58^{ab}	4.65^{d-h}
		81-95	5.14^{opq}	4.80^{h-m}	3.81^{h-k}
Gudenie		20-35	4.99^{pq}	1.49^{v}	2.11^{l}
	20	36-50	7.32^{e-j}	2.12^{s-v}	2.94^{kl}
		51-65	7.70^{d-h}	2.39^{p-v}	2.79^{l}
		66-80	7.07^{f-l}	2.29^{q-v}	2.80^{l}
		81-95	6.77^{g-n}	1.91^{tuv}	2.31^{l}
		20-35	7.27^{e-j}	2.23^{r-v}	2.49^{l}
		36-50	6.23^{h-q}	1.69^{uv}	2.31^{l}
	25	51-65	9.51^{abc}	3.62^{l-r}	2.65^{l}
		66-80	10.18^{a}	2.62^{p-v}	2.51^{l}
		81-95	7.00^{f-m}	2.23^{r-v}	2.45^{l}
		20-35	7.27^{e-j}	2.38^{q-v}	2.76^{l}
		36-50	9.61^{abc}	3.13^{n-t}	2.38^{l}
	30	51-65	10.00^{ab}	2.92^{o-v}	2.16^{l}
		66-80	6.90^{f-m}	2.03^{s-v}	2.18^{l}
		81-95	7.95^{d-g}	2.62^{p-v}	2.31^{l}
		20-35	7.44^{e-j}	2.31^{q-v}	2.55^{l}
		36-50	7.58^{e-j}	2.31^{q-v}	2.23^{l}
	35	51-65	7.31^{e-j}	2.35^{q-v}	2.16^{l}
		66-80	9.10^{a-d}	3.02^{n-u}	2.66^{l}
		81-95	7.09^{f-k}	2.35^{q-v}	2.34^{l}
		20-35	6.70^{g-n}	2.83^{o-v}	2.69^{l}
		36-50	7.18^{e-j}	2.81^{o-v}	2.39^{l}
	40	51-65	9.47^{abc}	3.82^{j-p}	2.44^{l}
		66-80	8.29^{c-f}	3.19^{n-t}	2.27^{l}
		81-95	8.61^{b-e}	3.39^{p-v}	2.69^{l}
SEM			0.53	0.52	0.31
CV (%)			13.0	22.0	14.9
LSD (5%)			1.47	1.46	0.87

Means with the same letter (s) with in a column of a variable were not significantly different at ($P < 0.05$). LT=mean yield of large tuber, MT= mean yield of medium tuber, ST= mean yield of small tuber. SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

4.4.2. Dry matter content

The analysis of variance indicated that dry matter content was significantly (P<0.05) affected by two way interaction of variety with tuber size as well as variety with intra row spacing (Table 8; Table 9; Appendix Table 3). The three way interaction as well as two way interaction of intra row spacing by tuber size had no significant on tuber dry matter content (Appendix Table 3). Variety Gudenie planted at intra row spacing of 40 cm gave the highest dry matter content (19.98%) followed by variety Gudenie planted at intra row spacing of 30 cm(19.96%), while the lowest (17.03%) was recorded from variety Jalenie planted at 35 cm intra row spacing (Table 8). The result indicated that variety Gudenie produced more dry matter content than variety Jalenie. The dry matter content observed in present study revealed the fact that late maturing varieties of potato had high dry matter content, which is indicated by variety Gudenie. This is due to the reason that as growing period of potato increased the dry matter of tubers also increased. Variation in tuber dry matter content might be attributed to the inherent varietal difference in the production of total solids (Bewuketu, 2012). Mangani *et al.* (2015) also reported as the dry matter content was affected differently for the different varieties. Dry matter content of varieties indicated the presence of considerable genetic variability (Amoros *et al.*, 2000). According to Elfinesh *et al.* (2011) high value of dry matter content were obtained from late matured varieties. Tesfaye *et al.* (2012) also found that dry matter content is governed by genetic factors. Tibebu *et al.* (2014) reported higher dry matter content of variety Gudenie than variety Jalenie. On the other hand, dry matter content also governed by plant population. The optimum density for optimal plant competition, plant with maximum use of light, water and nutrients, especially nitrogen, will produce high dry matter with increasing plant density decreased tuber dry matter content.The dry matter content of potato variety might higher in maximum light harvesting resulting in enhanced whole plant photosynthetic capacity (Tesfaye, 2009).

The interaction effect between variety and tuber size also indicate the highest (20.61%) dry matter content was recorded from variety Gudenie having tuber size of 66-80 g followed by variety Gudenie with tuber size of 81-95 g (19.61%),while the lowest (17.35%) value was recorded from variety Jalenie having tuber size of 51-65 g (Table 9). The tuber size from which potato tuber emerge might be influenced the production of dry matter content. Large seed tubers of 66-80 g produced relatively high dry matter content than others. This due to the possibility of large seed tubers could produced many amount of large tuber yield, which might result in high dry matter content. Mwansa (2002) reported that largest seed tuber size produced tubers with high dry matter content than small seed tubers.

Table 8. Interaction effect of variety and intra row spacing on quality parameters of potato in 2013/2014 at Nono Benja.

Treatments		Quality parameters	
Variety	Intra row Spacing (cm)	Dry matter content (%)	Tuber specific gravity (g/cm^3)
	20	17.35^{e}	1.059^{f}
Jalenie	25	18.25^{cd}	1.064^{de}
	30	18.77^{bc}	1.065^{d}
	35	17.03^{e}	1.061^{ef}
	40	17.35^{e}	1.064^{de}
	20	18.08^{d}	1.063^{de}
Gudenie	25	19.05^{b}	1.068^{c}
	30	19.96^{a}	1.073^{b}
	35	19.98^{a}	1.077^{a}
	40	19.77^{a}	1.077^{a}
SEM		0.22	0.001
CV (%)		4.6	0.4
LSD(5%)		0.61	0.0031

Means with the same letter (s) with in a column of a variable were not significantly different at (P < 0.05). SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

4.4.3. Tuber specific gravity (g/cm^3)

The interaction effect of variety and intra row spacing and variety by tuber size was significantly (P<0.05) affected specific gravity (Table 8; Table 9; Appendix Table 3). The highest (1.077) value of tuber specific gravity was obtained with variety Gudenie planted at intra row spacing of 35 and 40 cm followed by variety Gudenie planted at intra row spacing of 30 cm (1.073), while the lowest (1.059) tuber specific gravity was obtained with variety Jalenie planted at 20 cm (Table 8). On the other hand, the highest (1.074) tuber specific gravity was obtained with variety Gudenie having tuber sizes of 66-80 g and 81-95 g followed by variety Gudenie having tuber size 51-65 g (1.072), while the lowest (1.062) was obtained with variety Jalenie having tuber sizes of 20-35 g, 36-50 g and 51-65 g (Table 9). Tuber specific gravity was an indicator of acceptability of potato varieties for different processing purposes. The result obtained indicated Gudenie gave higher tuber specific gravity, but the values were increase with increasing intra row spacing (Table 8). This is because tuber specific gravity might be different among varieties which caused by genetic variability of varieties. On the other hand, there was also relatively increase in tuber specific value with increasing of tuber size, which due to the ample amount of reserve materials in large seed tubers that promote growth and development of plant and result in high tuber specific gravity. According to shayanowako *et al.* (2014), the specific gravity of tubers was higher at the intermediate stem numbers, which an indicator of growth performances of potato plant. Elfinesh *et al.* (2011) suggested that tuber specific gravity of potato was significantly influenced by varieties, and potato varieties having high specific gravity were acceptable in processing purposes like chips. The present study was similar with the findings of Tesfaye *et al.* (2013) who reported that varieties could be genetically different in tuber specific gravity. Bewuketu (2012) reported that Gudenie variety had high specific gravity than variety Jalenie. Helen *et al.* (2014) also reported the specific gravity value as it influenced by varieties and growing environmental. Potato tubers should have a specific gravity value of more than 1.080 for acceptability in quality for different processing purposes (Kabira and Berga, 2003).

Table 9. Interaction effects of variety and tuber size on quality parameters of potato in 2013/2014 at Nono Benja.

Treatments		Quality parameters	
Variety	Tuber size (g)	Dry matter content (%)	Tuber specific gravity (g/cm^3)
Jalenie	20-35	17.74^{ef}	1.062^{c}
	36-50	17.73^{f}	1.062^{c}
	51-65	17.35^{f}	1.062^{c}
	66-80	18.35^{de}	1.063^{c}
	81-95	17.58^{f}	1.064^{c}
Gudenie	20-35	18.70^{cd}	1.068^{b}
	36-50	18.66^{cd}	1.069^{b}
	51-65	19.26^{bc}	1.072^{a}
	66-80	20.62^{a}	1.074^{a}
	81-95	19.61^{b}	1.074^{a}
SEM		0.22	0.001
CV (%)		4.6	0.4
LSD (5%)		0.61	0.0031

Means with the same letter (s) with in a column of a variable were not significantly different at P < 0.05. SEM=Standard error mean, CV=Coefficient of variation and LSD=Least significance difference.

4.5. Correlation Analysis

The correlation analysis of parameters revealed that there were positive and negative associations among the studied variables of potato (Table 10). As observed from correlation analysis, the number of main stems (r = 0.15*), tuber number per plant (r = 0.63**), average tuber weight (r = 0.23*), marketable tuber yield (r =0.95**) and unmarketable tuber yield (r = 0.18*) was correlated significantly and positively (P<0.05) with total tuber yield (Table 10). These results showed that a positive association, in which increase in these variables might results in increment of total tuber yield. Khalafalla (2001) reported that tuber yield increased with increased number of stems per plant. According to shayanowako *et al.* (2014), the number of tubers per plant, increased with increasing number of stem per plant. On the other hand, negative and significant (P<0.05) correlations was observed between plant height (r = -0.20*) and total tuber yield. This indicates that as plant height increase there was a decrease in total tuber yield, because when height very high it might be reduce the tuber yield. Rajadurai (1994) reported that the plant height increased due to high plant population might be reduced tuber yield. Small tuber yield (r=0.13*) and medium tuber yield (r=0.17*) are positively and significantly (P<0.05) associated with total tuber yield. Small tubers could add to total tuber yield but had less amount, and the medium tubers also somewhat higher value than small tubers. The small tubers and medium tubers had low positive direct effect on total tuber yield (Tuncturk and Ciftci, 2005).

Average tuber weight (r = 0.36**) positively and significantly (P<0.05) associated with marketable tuber yield, medium tuber yield (r = 0.44*) and negatively associated with small tuber yield (r = -0.40**). This is due to average tuber weight could be increased with increment of marketability and decreased with small tuber yield which indicates as tubers became small there might be less average tuber weight, but with medium tuber it was medium weight. Larger tuber size associated negatively (P<0.01) with dry matter content (r = -0.39**) and tuber specific gravity (r = -0.34**). This is due to that the large the tuber the higher the water content and the lower solids content in large tubers. Smaller tuber size was positively and highly (P<0.01) correlated with Dry matter content (r = 0.50**) and tuber specific gravity (r = 0.56**). Dry matter content associated positively and highly (P<0.01) with tuber specific gravity (r = 0.88**). As tuber size increases there was an increase in water content and decrease in dry matter content, and tuber specific gravity become increase if dry matter is increase (Girma, 2012).

Table 10. Correlation between phenology, growth, yield and quality parameters of potato varieties at Nono Benja in 2013/2014

	DE	DF	DPhM	NS	PH	TN	ATW	MTY	UMTY	TTY	LT	ST	MT	DMC	TSG
DE	1	.73**	.67**	-.07ns	.54**	-.35**	-.23**	-.37**	-.14ns	-.35**	.42**	-.59**	-.57**	.46**	.49**
DF		1	.79**	-.24**	.54**	-.47**	-.53**	.53**	-.08ns	.46**	.46**	-.78**	-.75**	.50**	.51**
DPhM			1	-.18*	.48**	-.40**	-.34**	.48**	-.12ns	.43**	.33**	-.65**	-.65**	.45**	.47**
NS				1	.44**	.52**	.35**	.31**	-.29**	.15*	.06ns	.19*	.35**	.13ns	.06ns
PH					1	.06ns	-.03ns	-.17*	-.18*	-.20*	.41**	-.41**	-.34**	.57**	.42**
TN						1	.43**	.71**	.17*	.63**	.31**	.58**	.60**	-.01ns	-.21*
ATW							1	.36**	-.16*	.23**	-.11ns	-.40**	.44*	.08ns	.00ns
MTY								1	-.42**	.95**	.41**	.83**	.86**	-.24**	-.31**
UMTY									1	.18*	.25**	.49**	.21*	-.24**	-.34**
TTY										1	.41**	.13*	.17*	.28**	.36**
LT											1	-.05ns	-.04ns	-.39**	-.34**
ST												1	.79**	.50**	.56**
MT													1	-.38*	-.41**
DMC														1	.88**
TSG															1

ns,*, ** indicate non-significant, significant at 5% and 1% probability level respectively, DE= Days to emergence, DF=Days to 50% flowering, DPhM=Days to 50% physiological maturity, NS= Number of main stems, PH= Plant height, TN=Tuber number, ATW= Average tuber weight, MTY=Marketable tuber yield, UMTY=Unmarketable tuber yield, TTY=Total tuber yield, LT=mean yield of Large tubers, ST= mean yield of Small tubers, MT= mean yield of Medium tubers, TSG= Tuber specific gravity and DMC= Dry matter content.

5. CONCLUSIONS AND RECOMMENDATIONS

The effects of variety, intra row spacing and tuber size on potato growth, yield and quality parameters were investigated in 2013/2014 at Nono Benja District. This study confirmed the presence of significant influence of variety, intra row spacing and tuber size in the production of total tuber yield of potato at the study area.

The result from growth parameters indicated that plant height and number of main stems significantly affected by interaction effect of variety, intra row spacing and tuber size. Accordingly, the higher plant height from variety Gudenie with intra row spacing of 35 cm and tuber size 66-80 g, while shortest plant height was from variety Jalenie having tuber size of 36-50 g planted at intra row spacing of 40 cm. The higher number of main stems also observed from variety Jalenie having tuber size of 81-95 g planted at intra row spacing of 40 cm followed by variety Jalenie with tuber sizes of 66-80 g planted at intra row spacing of 40 cm. On the other hand, days to 50% emergence and days to 50% flowering were influenced by two way interaction i.e., variety by tuber size and intra row spacing by tuber size, and days to 50% physiological maturity was affected by one-way interaction effect of variety.

Yield parameters also influenced by interaction effect of variety, intra row spacing and tuber size. The result clearly indicated highest tuber number per plant was recorded from variety Jalenie with tuber size of 66-80 g planted at intra row spacing of 25 cm followed by variety Jalenie with tuber size of 81-95 g planted at intra row spacing of 20 cm. The highest average tuber weight from variety Jalenie having tuber size of 66-80 g planted at intra row spacing of 30 cm followed by variety Gudenie having tuber size of 66-80 g planted intra row spacing of 30 cm. Variety Jalenie planted at intra row spacing 25 cm using tuber size of 66-80 g gave highest total tuber yield and marketable tuber yield. The highest unmarketable tuber yield was recorded with variety Jalenie using tuber size of 81-95 g and planted at intra row spacing 20 cm.

In the present study, variety by intra row spacing and variety by tuber size significantly influenced potato quality parameters. Variety Gudenie planted at intra row spacing of 40 cm gave higher dry matter content followed by variety Gudenie planted at intra row spacing of 30 cm. In the same way, variety Gudenie having tuber size of 66-80 g also produced higher dry matter content. Variety Gudenie planted at intra row spacing of 35 cm gave higher tuber specific gravity. Similarly, variety Gudenie having tuber sizes of 66-80 g and 81-95 g gave higher tuber specific gravity. On the other hand, interaction effects of variety, intra row spacing and tuber size significantly influenced the mean yields of large, medium and small tubers. Variety Gudenie having tuber size of 66-80 g planted at 25 cm gave higher mean yield of large tubers. Variety Jalenie having tuber size of 66-80 g planted at intra row spacing of 25 cm gave higher mean yield of medium sized tubers. Variety Jalenie with tuber size 81-95 g planted at intra row spacing 20 cm gave higher mean yield of small tubers. Therefore, the study indicated the effects of variety Jalenie, intra row spacing 25 cm and tuber size 66-80 g gave higher performances in marketable and total tuber yield of potato at Nono Benja area.

The relationship among total and marketable tuber yield with average tuber weight and tuber number per plant was positive and highly significant. The number of main stems (r = 0.15*), tuber number per plant (r = 0.63**), average tuber weight (r = 0.23**), marketable tuber yield (r =0.95**) and unmarketable tuber yield (r = 0.18*) was significantly and positively correlated with total tuber yield. The correlation between days to 50% flowering and days to 50% physiological maturity with dry matter content (r = 0.51**) and tuber specific gravity (r = 0.47**) were positive and highly significant. The dry matter content and tuber specific gravity were positively and significantly correlated with total (r = 0.28**) and marketable tuber yield (r = 0.36**).

The overall result of the study showed that the interaction effects of variety, intra row spacing and tuber size significantly influenced yield and quality of potato at Nono Benja area. The three and two way interactions have showed superior performance in most growth, yield and quality parameters. According to the present study, higher marketable tuber yield per hectare was recorded by variety Jalenie with intra row spacing of 25 cm and tuber size of 66-80 g. However, since this study was conducted in single season and on single location with two varieties, it is advisable to repeat the study in multi-locations with more seasons and varieties to reach on conclusive recommendation.

In future further study on other agronomic practices of the crop is required in the study area. It appears to be worthy of conducting in-depth study on the impact of the factors on potato yield and quality during the rainy season in the study area. It may be important to conduct a study on processing quality of the recommended potato varieties in the area.

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9. APPENDIX

Appendix Table 1. The mean squares of ANOVA table for crop phenology parameters of potato at Nono Benja in 2013/2014

Source of Variation	DE	DF	DPhM
Rep	2.43ns	1.82ns	87.61ns
Variety	269.34**	5581.5**	18797.41**
Error (a)	0.56ns	0.42ns	40.54ns
Spacing	1.27ns	17.22**	56.62ns
Variety*Spacing	1.91ns	12.05**	41.21ns
Error(b)	0.69ns	1.59ns	62.13ns
Tuber size	1.06ns	1.04ns	81.64ns
Variety*Tuber size	2.76*	4.13ns	51.15ns
Spacing*Tuber size	1.96**	2.11ns	66.06ns
Variety*Spacing*Tuber size	1.28ns	3.10ns	68.73ns
Error (c)	0.85	1.96	62.69
Total			

DE= Days to 50% emergence; DF= Day to 50% flowering and DPhM=Days to 50% physiological maturity

Appendix Table 2. The mean squares of ANOVA table for growth parameters of potato at Nono Benja in 2013/2014

Source of Variation	PH	NS
Rep	15.15ns	0.14ns
Variety	4059.43**	36.67**
Error (a)	23.93ns	0.18ns
Spacing	75.90**	12.24**
Variety*Spacing	31.28**	1.78**
Error(b)	2.83ns	0.07ns
Tuber size	1413.21**	135.65**
Variety*Tuber size	113.17**	8.11**
Spacing*Tuber size	50.95**	1.24**
Variety*Spacing*Tuber size	31.10**	0.55**
Error (c)	6.77	0.09
Total		

PH= Plant height and NS= Number of main stems

Appendix Table 3. The mean squares of ANOVA table for yield parameters of potato at Nono Benja in 2013/2014

Source of Variation	TN	ATW	MTY	UMTY	TTY
Rep	0.39ns	23.39ns	14.10*	1.10ns	22.75*
Variety	38.34**	1116.08**	549.59**	6.30*	673.61**
Error (a)	0.19ns	2.67ns	4.32ns	0.16ns	6.00ns
Spacing	3.18**	352.48**	1.39ns	44.17**	48.39**
Variety*Spacing	1.48*	210.28**	23.26**	9.74**	56.48**
Error(b)	0.31ns	1.67ns	3.51ns	0.47ns	6.00ns
Tuber size	10.35**	168.13**	35.66**	2.16**	22.78**
Variety*Tuber size	0.98*	3.91*	13.65*	1.35**	22.65**
Spacing*Tuber size	1.06*	51.48**	21.29**	1.83**	34.13**
Variety*Spacing*Tuber size	1.05*	16.02**	19.55**	2.41**	32.28**
Error (c)	0.32	1.06	3.81	0.33	5.31
Total					

TN= Tuber number per plant; ATW= Average tuber weight; MTY= Marketable tuber yield; UMTY= Unmarketable tuber yield and TTY=Total tuber yield

Appendix Table 4. The mean squares of ANOVA table for quality parameters of potato at Nono Benja in 2013/2014

Source of Variation	LT	ST	MT	TSG	DMC
Rep	1.58ns	0.23ns	4.43**	0.000ns	0.03ns
Variety	91.71**	198.24**	358.70**	0.003**	98.32**
Error (a)	0.36ns	0.07ns	2.43ns	0.000ns	0.04ns
Spacing	1.57ns	2.73**	2.23**	0.000**	10.30**
Variety*Spacing	7.88**	1.91*	1.28ns	0.000**	7.60**
Error (b)	0.87ns	0.50ns	0.39ns	0.000ns	0.60ns
Tuber size	8.76**	0.60ns	7.34**	0.000ns	8.77**
Variety*Tuber size	3.96**	0.88*	4.65**	0.000*	2.94**
Spacing*Tuber size	4.30**	1.61**	2.68**	0.000ns	1.08ns
Variety*Spacing*Tuber size	2.95**	1.77**	3.10	0.000ns	0.93ns
Error (c)	0.83	0.25	0.86	0.000	0.76
Total					

LT= mean yield of Large tuber; ST= mean yield of Small tuber; MT= mean yield of Medium tuber; TSG= Tuber specific gravity and DMC=Dry matter content