EFFECT OF INFLORESCENCE REMOVAL AND TIME OF EARTHING-UP ON GROWTH, YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT JIMMA, SOUTHWESTERN ETHIOPIA

M.Sc. THESIS

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DEDICATION

This M.Sc. thesis work is dedicated to my brother, Masresha Fessiha, for his great sacrifice, support and encouragement.

STATEMENT OF THE AUTHOR

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BIOGRAPHICAL SKETCH

The author, Dessie Fessiha, was born on 15 September 1992 in Debre Tabor, South Gonder Zone in the Amhara Regional State, Ethiopia. He followed his elementary education from 2001 to 2008 at Wowa Mariam Junior Elementary School and his secondary education from 2009 to 2010 at Dagmawi Tewodros Secondary School, and his preparatory education from 2011 to 2012 at Dagmawi Tewodros Preparatory School in Debre Tabor town. He joined Addis Ababa University College of Agriculture and Veterinary Medicine, selale Campus in 2013, and graduated with the Degree of Bachelor of Science in Plant Science in 2015. After graduation, he joined the School of Graduate Studies at Jimma University in October 2015 to pursue his study leading to the Degree of Master of Science in Horticulture.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CSA	Central Statistical Agency
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	The Food and Agriculture Organization Corporate Statistical Database
HARC	Holeta Agricultural Research Center
RCBD	Randomized Complete Block Design
SAS	Stastistical Analysis System

ABSTRACT

Potato is a high potential food security crop in Ethiopia. However, yield and productivity of the crop has been far below the world average. This is due to several factors including inappropriate agronomic practices, such as time of earthing-up and inflorescence management. Field experiment was conducted at Jimma, Southwest Ethiopia during 2016/17 under irrigation to determine the effect of time of earthing-up and inflorescence removal on growth, yield and quality of potato. The treatments consisted of time of earthing-up (no earthing-up, earthing-up at 15, 30 and 45 days after complete plant emergence) and inflorescence removal (inflorescence removed and not removed). Potato variety (Belete) was used for this experiment. A 2x4 factorial experiment was laid out with 3 replications. Data collected on growth, yield and quality components of potato were analyzed using SAS Version 9.3 statistical software. Inflorescence removal affected majority of the growth and yield parameters, while time of earthing-up affected all growth, yield and quality (green tuber number) parameters. The tallest plant height (87.3 cm) and the largest number of main stem per plant (4.3) was recorded from plants that received earthing-up at 15 days after plant emergence. The widest plant spread (64.83 cm), the largest leaf area (37cm^2)and the largest stem diameter (7.8 cm) were recorded from plants that received earthing-up at 15 days and inflorescence removal. Likewise, earthing-up at 15 days, combined with inflorescence removal, gave the maximum marketable tuber yield (35.83 ton/ha), and the highest average tuber weight per plot (120.37g). The highest total tuber yield (41.6 ton/ha) was recorded from plants that received earthing-up at 15 days combined with inflorescence removal, followed by earthing-up at 30 days combined with inflorescence removal (37 ton/ha), earthing-up at 45 days combined with inflorescence removal (33 ton /ha)and no earthing-up (31 ton /ha). The least number of green tubers per hill (1.47) was recorded from earthing-up at 15 days after complete plant emergence. Earthing-up at 15 days in combination with inflorescence removal (at 60 days after complete plant emergence) gave better plant growth, maximum tuber yield of Belete potato variety under irrigation condition. Since the current research was conducted at one location, in one season, and with one potato cultivar (Belete), it would be advisable to repeat the experiment so as to arrive at a final conclusion and subsequent recommendation.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.), belonging to the Solanaceae family, is an annual, herbaceous, tuber crop ((Ekin, 2011). It originates in the Andes mountain of South America on the border between Bolivia and Peru 8,000 years ago (Oztruk *et al*., 2010).

Potato is one of the most important food crops, both in developing and developed countries of the world (Ekin, 2011). The total volume of world production in 2015 was more than 376.45 million ton from a total area of 19.34 million hectares, and in Ethiopia the same year 775,503 ton of potato was produced from 69,999 hectares (CSA, 2015). It is a high potential food security crop in Ethiopia due to its high yield potential, nutritional quality, short growing period, and wider adaptability (Tewodros *et al*., 2014).

Despite its importance as a food crop, the productivity of this crop in Ethiopia is very low (Gebremedhin *et al*., 2008). The low productivity of potato is attributed to many factors, including poor agronomic practices, such as earthing-up, inflorescence removal, soil moisture, lack of sustainable supply of improved planting material, high cost of seed tubers, disease and pest problem, inadequate storage, among others (Gulluogul *et al.,* 2012).

Various researchers (Adane *et al*., 2010) indicated that application of proper cultural practice can play an important role in improving growth and yield of potato crop. Among the cultural practices, time of earthing-up and inflorescence management are critical to improve tuber yield and quality (Asl, 2016). Inflorescence removal can decrease the competition for assimilate between flowers and tubers (Nazari, 2010).

In most potato growing areas of Ethiopia, the majority of potato cultivars produce flowers (Tekalign and Hammes, 2005). Flowering and tuber initiation in potato are interlinked (Struik, 1991), and developing flower has a considerable effect on the growth of roots, shoots and leaves (Lahotti, 2003). Koochaki *et al*. (1997) indicated that growth period of tuber in potato occurs during 30-60 days through a linear method at the time of flower formation on the main stem and branches. According to Almekinders and Struik (1996), flowers and tubers compete to acquire assimilates, and pruning of flowers would increase transferred assimilates into underground structures and increase tuber yield. Paul *et al.* (1989) reported the existence of competition between vegetative and reproductive organs in plants. Nazari (2010) and Tekalign and Hammes (2005) studied the effect of inflorescence removal on potato tuber yield, and reported tuber yield increase of 9 and 18 percent, respectively, when the inflorescence was removed.

Earthing-up influences the pattern of stolon formation, that is, number and size of stolon, and the structure of the stolon system (Chala, 2016). According to Pavek and Thorthon (2009), appropriate time of earthing-up provides a good cover for the newly formed tubers and ensures the developing tubers covered with an adequate layer of soil. In addition, earthing-up has various advantages, including covering the applied fertilizer and preventing it from a possible loss, gets rid of weeds thus preventing competition between potato plants and weeds, loosens the soil this again helping potato plants to better develop roots, makes water flow more easy within the furrows and prevents flooding during rainy season, improves environmental condition of the plants and the soil, it also covers potato tubers forming close to the surface of the soil hence reducing the risk of damage from potato tuber moth and greening. Earthing-up (when not applied timely and appropriately) may have disadvantages (Tamiru, 2004) in that it can damage potato plant root system, and cause lesions on the roots and tubers, thus increasing the risk of disease. Improper earthing-up practice can adversely affect potato tuber yield, and up to 8% yield loss was reported due to poor earthing-up of the potato crop during its growth cycle (Gebremedhin *et al*., 2008).

Farmers in various parts of Ethiopia (including Oromia National Regional State), practice eathing-up at different times (Chala, (2016)). One of the main challenges associated with potato production in most parts of Ethiopia is lack of information on specific management practices. According to CSA (2016), potato in Ethiopia covers an area of 296,577 ha with a total production of 3,657,638 ton. This amount is still low compared to the world average potato production, The major bottle necks limiting potato prodaction in Jimma area include, poor agronomic practices, such as earthing-up, inflorescence removal, soil moisture, lack of sustainable supply of improved planting material, high cost of seed tubers, disease and pest problems.

Tekalign and Hammes (2005) conducted a research at Haramaya to assess the influence of cultivar and reproductive growth on growth and productivity of potato, and has confirmed flower removal to result in an increased potato tuber yield. Relatively recently, studies have been conducted, at Degem (North Shewa Zone) and Jimma (Jimma Zone), to assess the effect of time of earthing-up on growth, yield and quality of Jalene potato cultivar (Tesfaye Getachew *et al*., 2012; Tadele Fanos *et al*., 2016), and the results revealed that earthing-up at 15 days after emergence gave superior performance with regard to growth and yield response variables (parameters) under rain-fed condition. However, a combined effect of time of earthing-up under irrigated condition, and inflorescence removal has not been assessed yet. The present work therefore was initiated with the following objectives:

- To determine the effect of time of earthing-up and inflorescence removal on growth, yield and quality of potato tuber,
- To assess a possible interaction effect of time of earthing-up and inflorescence removal on growth, yield and quality of potato tuber.

2. LITERATURE REVIEW

2.1. Origin, Distribution and Importance of potato

Potato (*Solanum tuberosum* L.) is an annual, herbaceous, tuber crop which belongs to the family of Solanaceae. The chromosome number of wild potato is 2n = 24, while the cultivated has 2n = 48. It is a dicotyledonous, herbaceous perennial plant that is treated as annual, since the edible portion of the plant is uprooted and used each year (Santos and Gilreath, 2004). It has pinnately compound pattern alternate leaves on its above ground stem and specialized underground storage stems or tubers (Decoteau, 2005). It is moderately frost tolerant and a C_3 plant with a low light saturation point (Hausler *et al.,* 2001). Potato has five distinct growth stages: sprout development, vegetative growth, tuberization (tuber formation), tuber bulking, and tuber maturation. It has fibrous adventitious root system. This develops just above the nodes on underground portion of the stem (Ekin, 2011).

The potato originates from South America, most likely from the central Andes in Peru (Dehder, 2007). It is indigenous to Andean region from Venezuela to northern Chile and Argentina (Faramarzi 2011). According to this author, the potato was domesticated and has been grown by indigenous farming communities for over 4,000 years.

Potato is the world's leading vegetable crop and is grown in 79% of the world's countries (Muhammad *et al.*, 2013). More than a billion people consume potato almost daily, and hundreds of millions of people in developing countries depend on potatoes for their survival (FAO, 2008). It was introduced to Ethiopia in the 19th century and is found widely distributed in the high land and mid-altitude areas of the country (Girma, 2001). Hence the Ethiopian government has identified potato as one of the priority crops of the agricultural growth programme (Tafi *et al.,* 2010).

Potato serves as food and cash crop for smallholder farmers, and occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops (Yigzaw *et al.,* 2008). As a food crop, it has a great potential to supply high quality food within a relatively short period and is one of the cheapest sources of energy.

Moreover, the protein from potato is of good composition with regard to essential amino acids in human nutrition (Berga *et al.,* 1994). The potato tuber is known to supply carbohydrate, high quality protein and a substantial amount of essential vitamins, minerals, and trace elements (Framarzi*et al.,* 2011). Moreover, the potato crop provides more nutritious food per unit land area, in less time, and often under more adverse conditions than other food crops (Yigzaw *et al*., 2008). It is said to be one of the most efficient crops in converting natural resources, labour and capital into a high quality food with wide consumer acceptance. The average composition of the potato tuber is about 80% water, 2% protein, and 18% starch (Tacio, 2009).

2.2. Status of Potato Production in Ethiopia

In Ethiopia the potato crop is mainly grown at altitudes ranging between 1,500 and 3,000 masl by smallholder farmers, which accounts for over 90% of the production (Abebe Chindi *et al*., 2013). It is a very important food and cash crop, especially in the highland and mid altitude areas (Berga *et al.,*1994).

Potato is widely grown in various parts of Ethiopia (Yigzaw *et al*., 2008). The north-western area, situated in the Amhara region, is one of the major potato growing areas in the country, and it constitutes about 44.96% of the total potato production. South Gondar, North Gondar, East Gojjam, West Gojjam and Awi zones are the major potato production zones (Muhammad *et al.*, 2013). Oromia region is another suitable area of potato production in the country (CSA, 2016), accounting for about 38.17% of the potato production. West Shewa, North Shewa and West Arsi zone are the major producing zones. The Southern Nations, Nationalities and Peoples Region (SNNPR), is another major potato growing area in the country, accounting for about 16.62% of the potato production(Girma, 2001). The major potato producing zones in the SNNPR are Gurage, Gamo Goffa, Hadiya, Wolyta, Kambata, Siltie and Sidama (Gebremedhin *et al*., 2012).

Quality potato seed is one of the most important ingredients for successful potato production. Potato is regarded as a high-potential food security crop due to its ability to provide high yield and quality produce per unit input with a short crop cycle (mostly <120 days). Potato growth and quality are influenced by environmental factors such as temperature, moisture, light, soil type and nutrients supply. Factors that influence growth of the crop can be controlled by the grower including variety of potato, size of mother seed tubers, plant stand, stem population, moisture, nutrition, pest management, planting and harvesting date. Only when all factors are at their optimum levels that the most profitable yield and quality of potatoes can be attained (Chala, 2016).

2.3. Factors Affecting Growth and Yield Components of Potato

2.3.1. Earthing-up

Earthing-up in potato is an important agronomic practice. It involves drawing mounds of soil up around the plant to prevent new tubers from growing and turning green and poisonous, tuber moth and blight infection. Potatoes are a shallow rooted crop; hence care is needed to avoid excessive cultivation (Gullougul, 2009). Earthing-up has been reported to have an effect on potato tuber yield. Up to 8% yield loss was reported due to poor earthing-up of the potato crop during its growth cycle (Gebremedhin *et al.,* 2008). After applying the top dressing of urea fertilizer, potatoes should be earthed up 20 to 30 cm high. The first earthing-up will be the first weed control.

Earthing-up provides a form of weed control and enables the plant to absorb more nutrients due to freedom from weed competition and resulting in increased yield compared to no earthing-up treatment (Muhammad *et al.*, 2013). Qadir (1997) reported significantly the highest number of tubers per plant at 15 days earthing-up after complete plant emergence. According to Tafi *et al*. (2010), when potatoes are earthed-up to 10 cm high, the length of underground stems was increased which ultimately increased tuber number per plant. Tesfaye *et al*. (2012) similarly reported that cultural practices given to the plant during active growth stage can create favorable soil conditions for the initiation and development of more number of tubers and this in turn increases tuber number.

Time of earthing-up depends on the plant growth stage, soil temperature and moisture conditions (Tafi *et al.,* 2010). Potato plants which received earthing-up when they reach to a height of 25 to 35 cm gave better vegetative growth and encouraged the underground growth and increased the number of stems (Berga, 2008). According to the above authors, earthing-up facilitated dry matter accumulation in tubers and increased tuber yield. The authors further explained that the effect of earthing-up was significant from the tuber yield characteristics point of view, which indicates different reactions among different varieties towards appropriate time of earthing-up in relation to the physiological growth stages of the plant. Similarly, Muhammad *et al.* (2013) reported that minimum number of stems per plant was recorded in plants grown on unleveled land, followed by tubers planted in furrows without ridges. Potato planted on plain, wide beds and covered from one side gave maximum number of stems per plant. This may be due to a better aeration that might be created as a result of earthing-up that provided suitable condition to the tubers in this planting system.

Qadir, (1999) investigated the effect of earthing-up at different stages of growth, i.e. no earthing-up (control), two, three, four and five weeks after complete emergence of potato plant on the performance of potato cultivar ‘Cardinal’, in terms of various growth and yield parameters under the soil and climatic conditions of Peshawar, Pakistan. The result indicated that plant height (47 cm), plant spread (51.75 cm) after 60 days of planting, number of stems per plant (3.82), number of tubers per plant (7.75) and yield per hectare (21.44 t/ha) were significantly higher when plants were earthed-up two weeks after the complete emergence of the potato plant. Minimum number of green potatoes (3.5) was recorded in plot which was earthed-up two weeks after the emergence. Similarly, Qadir (1997) also reported that plant height (49.04 cm), plant spread after 45 days (36.73 cm) and 60 days after planting (49.37 cm), number of stems per plant (4.44), tubers per plant (9.00), yield per hectare (17.29 t/ha) were significantly higher when plants were earthed-up two weeks after the complete plant emergence. In a similar manner, minimum number of green potatoes (5.5) was recorded in potatoes which were earthed-up two weeks after the complete emergence of the potato plant.

Earthing-up could increase the tuber number per plant and tuber yield significantly, compared to no earthing-up, mainly due to improvement of total tuber yield and decrease in tuber greening (Tafi *et al.,* 2010). Soil adding significantly increased average tuber weight, the potential average tuber weight that can be successfully produced by time of earthing-up with the tuber numbers per bush, tuber yield and environmental conditions during the initiation phase of growth (Qadir (1997). According to Qadir *et al*. (1999), higher tuber diameter was recorded at 15 days earthing-up after complete plant emergence. Gebremedhin *et al.* (2008) also reported that earthing-up compared to no earthing-up significantly increased yield components of potatoes.

Yield of potato is strongly affected by the size of the leaf area and the duration of photosynthesis (Van Oijen, 1991; Boyd *et al*., 2001). The report of Qadir *et al*. (1999) revealed that better yield and yield components of potato including leaf area were recorded from those plants received earthing-up two weeks after emergence. According to Tadele *et al.* (2016) earthing-up at 15 days after plant emergence might have supported the plants by creating improved soil aeration, better root growth for nutrient absorption and in turn increased plant growth and leaf area. Earthing-up can be effective for late blight management strategy as long as intact soil is present over the surface of the tubers (Tesfaye *et al.,* 2012). Proper earthing-up is one of the most important agronomic practices that affect yield and quality of potato tuber (Rani, 2010). This practice is carried out to protect tubers from direct sunlight (which potentially causes greening of tubers), high temperature and insect injury such as potato moth. Bohl (2010) also reported that earthing up had significant effect on tuber number and average tuber weight per hill and tuber yield per hectare and in all the cases the earthed-up plots gave the highest value compared to the non-earthed-up plots.

Earthing-up at 15 days after complete plant emergence matches with active growth stage of the plant, thus it enhanced continuous vegetative growth and as a result, maturity will be delayed (Tesfaye *et al.,* 2012). The number of days to reach maturity is the important parameter for potato producers in that, it enables the growers to develop a suitable production scheme, season and (Adane *et al.,* 2009).

2.3.2. Inflorescence removal

The most efficient sources of potato are leaves, while the sinks are tuber, root and rapid growing tissues (Robert and Dwelle, 1990). Majority types of potatoes produce flowers and these organs are known to consume the created nutrient (Khajepoor, 2006). Flowering period in potato starts at the same time of growth period of tubers (Sarmadnia and Koochaki (1993). Inflorescence removal in potato increased side growth through arresting apical dominance of stem (Asl,2016). Nazari (2010) reported significant increase in size of stem of potato due to inflorescence removal. Removal of apical buds resulted in side growth of branches and this has delayed maturity. Salisbury and Ross (1992) indicated the existence of apical dominance in the stems of most plant species and the removal of the terminal flower favors the growth of lateral buds and thereby increases branching.

There is an intense competition between tubers and inflorescence for assimilates, and the removal of inflorescence can increase tuber diameter due to the removal of a competing sink (Almekinders and Struik, 1996). Framarzi (2011) also reported that inflorescence and tubers of potato compete to attract assimilates, and pruning of flowers would increase translocation of photo-assimilates to underground structures to increase the yield of tuber. The initial growth of flower needs a considerable amount of available assimilates in order to produce mature flowers. Paul *et al.* (1989) stated existence of an interplant competition between vegetative and reproductive organs of plants. According to Ho and Hewitt (1986), inflorescences situated nearer to the leaf are known to be the main consumer of assimilates.

Inflorescence removal is a means to reduce competition between tubers and inflorescence for assimilates (Fisher *et al.,* 2002). Nazari (2010) and Tekalign and Hammes (2005) reported tuber yield increase of 9 and 18 percent, respectively, when the inflorescence was removed.

Pruning of reproductive parts allows assimilates to be distributed to the tubers (Asl, 2016). According to Lahooti *et al.* (2003), inflorescence removal increases number of leaves per plant. These authors further stated that apical bud, flower buds and growing inflorescence on the stem are auxin sources and deterrent of tuber development. Pruning of flowers resulted in higher leaf area (Nasrollahzade *et al.*, 2005) and which is essential for higher biomass and tuber yield.

Inflorescence removal significantly increased number of tubers per plant (Sarmadnia and Koochaki, 1993). This is because, when the apical buds and inflorescence/fruits are removed, competition between flowers and tubers for assimilates, will in turn, be reduced and more tubers formed. Nazari (2010) reported an increase in number of tubers per plant as a result of inflorescence removal. Also Tekalign and Hammes (2005) reported that flower production can reduce the number of tubers per plant. Koochaki *et al.* (1997) similarly reported that developmental stages of tubers in potato occur same time when flowers are formed on the main stem and branches. According to Almekinders and Struik (1996) and Faramarzi *et al.* (2011), flower removal improves the flow of assimilates to the underground structures and increases tuber weight, as it arrests competition between flowers and tubers of potato compete to attract assimilates. Similarly, inflorescence removal increases tuber diameter (Nasrollahzade *et al.,* 2005).

2.4. Sink and Source Relation in Potato

Developing flowers are strong sinks for mineral nutrients, sugar and amino acids, and there is a corresponding decrease in the amounts available for the growth of other plant parts of the potato (Famiani *et al*., 2000). Depending on the strength of the sinks, potato plants allocate assimilates to the developing fruit, tubers and other vegetative structures. Under conditions of assimilate limitation, competition among sink organs is very high (Lahoti *et al.,* 2003). The process of carbon assimilation and partitioning is believed to be a major determinant of crop yield (Asl, 2016). In potato, carbon, fixed during photosynthesis is either directly metabolized to provide energy and carbon skeletons for the cell's own respiration and growth, or it is exported, mainly in the form of sucrose, to other organs to support their growth and development and/or to provide assimilates for the synthesis of storage compounds. Therefore, the organs in potato can be generally divided into source and sink organs (Nazari, 2010). Source organs that are usually photosynthetically active are defined as net exporters of photo-assimilates, represented mainly by mature leaves, and sink organs that are photosynthetically inactive are referred to as net importers of fixed carbon. Sinks can be further divided into two different classes: utilization and storage sinks. Utilization sinks are highly metabolically active at rapidly growing tissues such as meristems and immature leaves, while storage sinks are the organs like tubers, seeds and roots, where the imported carbohydrates are deposited in the form of storage compounds (*e.g.* starch, sucrose, fatty acids, or proteins) (Almekinders and Struik, 1996). The storage sinks are usually specialized for other essential processes, such as mineral acquisition (roots) or reproduction (seeds, fruits and potato tubers). Metabolic sink or source status of a particular organ is under developmental control. For example, immature leaves are metabolic sinks while after maturation leaves become photosynthetically active sources. Growing potato tubers are storage sinks, however during sprouting they turn into source organs where the stored compounds are mobilized to provide transportable organic nutrients for the growth of the buds. The evolution of sink and source organs in potato generates the need of resource allocation between sink and source organs, which is a major determinant of potato tuber productivity. Sucrose is the main form of carbohydrates transported from source to sink tissues (Farmazi *et al*., 2011).

2.5. Tuberization

Potato tuber is defined as a shortened and thickened modified stems that bear scale leaves (cataphylls) each with a bud in its axle (Cutter, 1978). If a whole tuber or piece of tuber containing one or more eyes is planted, the buds sprout and a plant develops above the ground (Struik, 1999). Well before plant emergence the developing sprout grows adventitious roots, which constitute the root system. Also developing from the underground portion of the stem are stolons, which may bear new tubers at their tips (Ewing, 1985). The stolon tips are the usual site of tuber formation. Stolons are diagravitropic stems with long internodes and scale leaves. They develop as branches from underground nodes and are terminated by a curved apical portion called a hook (Peterson *et al*., 1985). Stolen formation starts at the most basal nodes and progresses acropetally. Asl (2016) investigated the pattern of stolen formation in three cultivars and found that about half of the stolons were formed at the most basal node, with roughly 10% of the remaining stolons at each of the next four higher nodes.

The potato plant is known for its plasticity in organ development (Steward *et al*., 1981). Ewing (1985) and Marinus (1993) reported that tuber formation can occur on almost every bud of the plant including auxiliary bud. The signal for induction to tuberization is omnipresent (can be transported to every plant part) and can express itself in all buds (Struik *et al*., 1999).

2.6. Effect of Earthing-up Time and Inflorescence Removal on Potato Tuber Yield

The tubers originate from the tips of stolons, and occasionally tubers form along the stolon itself (Mahmoodaba *et al.,* 2010). The initiation of young tubers at the tips of the stolons usually occurs when the plants are 15 to 20 cm high, or from 5 to 7 weeks after planting (Spooner, 2010). Tuberization is affected by many environmental factors, and depends largely on translocation and storage of carbohydrate reserves in excess of that needed by other parts of the plant in its growth (Tadele *et al.,* 2016).

Tafi *et al*. (2010) reported that soil adding to the plant affects potato product structure. The authors further stated that this is due to appropriate time of the soil adding for active physiological growth stages that create favorable soil environment for the growth and development of the plant.

Late earthing-up treatments appeared not to affect soil temperatures, and all early earthing up treatments yielded significantly more than the treatment that was not earthed-up and lately earthed treatments(Mahmoodaba *et al*., 2010). Similarly, Tadele *et al*., (2016), reported that time of earthing-up had a significant effect on the percentage of potato yield per unit area.

Inflorescence removal can increase tuber yield through increasing tuber size. Nasrollahzade *et al*. (2005), Nazari (2010) reported an increase of marketable yield of potato up to 2.68 ton/ha (8.9 percent) due to inflorescence removal. Koochaki *et al*. (1997) reported that flower development significantly affected the available assimilates due to changes in patterns of assimilate production and its allocation to the upper and underground plant reservoirs.

2.7. Potato Tuber Quality

Quality of tuber crops can be affected by cultural practices, including fertilizer management (Öztürk *et al*., 2010), irrigation schedule, cultivar differences (Story, 1992; Abbasi *et al*., 2011). The physiological age of the seed tuber, the cultivar, the soil type, climatic conditions during the growing period as well as agronomic factors like foliage killing and reproductive organs (Firman and Allen, 2007).

2.7.1. Specific gravity

Specific gravity is the most widely accepted measurement of potato quality (Ekin, 2011). There is a very high correlation between the specific gravity of the tuber, the starch content and also the percentage of dry matter (Hegney, 2005). Based on specific gravity value; tubers can be classified as low (< 1.077), intermediate (1.077 ≤ X ≤ 1.086), and high (> 1.086) specific gravity grades. Kabira and Berga (2003) reported that good quality potatoes should have a specific gravity value of more than 1.080. Potato tubers with specific gravity values less than 1.070 are generally unacceptable for processing. The lower tuber specific gravity may result in poorer processing quality (Storey and Davice, 1992). Specific gravity is the weight of the tuber compared to the weight of the same volume of water (Henderson, 2000). According to Hegney (2005), specific gravity is used as an estimate of the solids or dry matter content of tubers and the higher the dry matter content the lower the water content and the higher the specific gravity. Lower specific gravity potatoes are more costly to process, because more water must be fried out of such potatoes in order to meet minimum quality standards. Consequently, more potatoes must be processed in order to produce the same volume of product and the longer fry time results in the absorbing of more fat into the processed product making it (Hegney, 2005). High specific gravity potatoes are better suited for baking, frying, mashing and chipping; low specific gravity for boiling and canning. The potato chip manufacturers prefer potatoes of high specific gravity. Also, specific gravity is highly correlated with dry matter content, and the lower tuber specific gravity may result in poorer processing quality (Hogy and Fangmeier, 2009).

2.7.2. Dry matter

The dry matter or 'solids content' of tubers is one of the prime characters used by potato processors to evaluate a crop. Potato tubers with high dry matter content are most suitable for the manufacturing of dehydrated food products and stock feed and is especially good for the production of fried foods (Hegney, 2005). Tubers with high dry matter content are better texture and more economical to process. Potato tubers with dry matter contents greater than 20% are the most preferred for processing of tuber into different potato products (Kabira and Berga, 2003). Dry matter content can be modified by production system and climatic factors, such as, solar radiation, soil moisture, and air temperature (Storey and Davies, 1992). In growing potato tubers, starch concentration increases towards maturity and thus, mature tubers have high starch and protein concentrations, but are low in sugar. Therefore, the length of growing period of tubers has an important effect on starch concentration of harvested tubers (Ekin, 2011).

Storey and Davies (1992), reported that the dry matter content of potatoes is largely governed by the weight of processed products, which could be obtained from a given weight of raw tubers. According to these authors dry matter content of the potato tuber is one of the main determinants of quality for both processing as well as cooking since high dry matter content with less sugar accumulation and water content were desirable.

2.7.3. Green tuber

Earthing-up reduces the percentage of green tubers, especially in lighter soils (Rani., 2010). One time earthing-up compared to no earthing up of the potato crop during the growing period, increased the potato yield by 10 to 20 % (Gebremedhin *et al.,* 2008). Potato tubers exposed to direct sun light develop a green pigment leading to greening (Pavek and Thornton, 2009), which in turn, affects quality of the potato tubers.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted at the Jimma University College of Agriculture and Veterinary Medicine; horticulture and plant sciences research site from December 2016 to March, 2017. The site is located in the Oromia National Regional State, Jimma Zone, Jimma woreda which is 356 km southwest of Addis Ababa at about 7^o, 41^oN latitude and 36^o, 50 longitudes at an altitude of 1710 m. a. s. l and the area receives annual rainfall of 1250 mm. The mean maximum and minimum temperatures are 28^0C and 11^0C, respectively. The mean maximum and minimum relative humidity are 91.4% and 39.92%, respectively (CSA, 2016).

3.2. Experimental Material

The potato variety, Belete, was used for this experiment due to its high yielding and wide adaptability nature. The national recommended spacing for the Belete variety is 75 cm and 30 cm between rows and plants, respectively. The average yield for this variety is 46 ton/ha in research field and 37 ton/ha at farmers field. Some details of description of the Belete variety are given in Table 1.

Table 1. Description of Belete variety

Variety	Year of release	Research station	Altitude (m.a.s.l)	Rainfall (mm)	Days to maturity	Plant height (cm)	Flower color
Belete	2009	Holleta	1600-2800	750-1000	120	76	White

3.3. Treatments and Experimental Design

In this experiment two factors were considered *viz.* time of earthing-up, with four levels (0, 15, 30 and 45 days after complete plant emergence), and inflorescence removal, with two levels (inflorescence removed and not removed). The experiment was a 2x4 factorial, laid out as a randomized complete block design with three replications (Table 2) and was conducted under irrigation condition. A plot size of 3mx3m was used and the distance between plots and the blocks were 0.5 and 1 meter, respectively.

3.4. Treatment Combinations

Table 2. Treatment combinations

S.N	Treatment combinations
1	No earthing-up + No inflorescence removal
2	No earthing-up + Inflorescence Removed
3	Earthing-up at 15 days* (standard check) + No inflorescence removal
4	Earthing-up at 15 days + Inflorescence Removed
5	Earthing-up at 30 days + No inflorescence removal
6	Earthing-up at 30 days + Inflorescence Removed
7	Earthing-up at 45days + No inflorescence removal
8	Earthing-up at 45days + Inflorescence Removed

*All earthing-up days are after full emergence (15, 30, 45 days)

3.5. Experimental Procedure

3.5.1. Experimental field preparation

The experimental field was ploughed to a depth of 25-30 cm and well prepared. Ridges were made manually after leveling. Planting was done by selecting well sprouted seed tubers. Recommended N and P chemical fertilizer in the form of diammonium phosphates (195 kg/ha) and urea (165/kg) was applied. Diammonium phosphates was applied at time of planting while half of N source was applied at time of planting and the remaining half at the time of first earthing up (two weeks after emergence).

Harvesting: Harvesting was done at physiological maturity when the leaves of the potato plants senesced. Two weeks before harvesting, the haulms of the potato plants were mowed using a sickle to toughen the tubers and avoid bruising during harvesting. Harvesting was done by hand using hoes.

3.5.2. Earthing-up

Earthing-up was done manually at 15, 30 and 45 days after complete plant emergence by using hand hoe so as to attain ridges of 20 cm height (Tadele *et al*., 2016).

3.5.3. Inflorescence removal

Inflorescence removal was carried out at the start of flowering (formation of flower buds), that is, 60 days after emergence of potato plants, and was removed by hand from peduncle (from each hill of all flowering buds) (Nazari *et al.,* 2010).

3.6. Data Collected

3.6.1. Growth parameters

Leaf area (cm^2): It was determined by measuring the length and width of all leaves of five randomly sampled plants from two middle rows in each plot.

Plant spread (cm): It was measured by using the main branches from east to west and north to south direction and the average of 15 plants was taken as plant canopy width.

Plant height (cm): It was measured at full blooming from the ground level (from the base of the main shoot) to the tip (apex) from randomly taken 15 plants from the middle two rows of each plot.

Number of main stem/hill: The number of main stems was recorded by counting only stems that emerged from the seed tuber as single stems from 15 plants per plot middle two rows

Stem diameter (cm): It was measured at full blooming from randomly taken five plants from the middle of the main stem by digital caliper and the average was taken.

Days to maturity: It was recorded when 50% of the plants in each plot become ready for harvest (when haulms showed senescence).

3.6.2. Yield and yield components

Average tuber number (ATN) /hill: This was determined by dividing total number of tubers per plot by the total number of plants in the net plot.

Average tuber weight (ATW) (g): It was determined by dividing total fresh weight of tubers per plot by the total number of tubers.

Marketable tuber yield (MTY) (ton/ha): Healthy tubers weighing greater than or equal to 25 g were considered as marketable (Girma *et al.,* 2001).

Unmarketable tuber yield (UMTY) (ton/ha): Tubers with physical damage, abnormal shape, tubers weighing less than 25 g, rotten, green and cracked tubers were considered as unmarketable.

Total tuber yield (TTY) (ton/ha): It was determined as the sum of the weights of marketable and unmarketable tubers from the net plot area and was expressed in ton per hectare.

3.6.3. Quality Parameters

Tuber dry matter content (%): It was determined by taking a representative tuber sample from each treatment, in which tubers were sliced and 200 g (fresh weight) was taken, and oven dried at 80^0C for about 72 hours until constant weight was obtained.

Tuber specific gravity: Specific gravity of tubers was determined by harvesting five kg tuber from the middle two rows.

Specific gravity was calculated based on the following formula:
Specific gravity = (weight in air) ÷ [(weight in air) - (weight in water)]

Green tubers: Tubers colored green due to exposure to direct sunlight were counted per hill.

3.7.Data Analysis

The data were collected per plot basis, checked for meeting all the ANOVA assumptions and subjected to analysis of variance using SAS Version 9.3 statistical software (SAS Institute Inc., 2002). Treatment means were separated by using LSD value at 5% significant level and correlation analysis among studied parameters was also made.

The following model for factorial RCBD was used.

$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \epsilon_{ijk}$

i =1… inflorescence removal,
j =1, 2… Earthing-up,
K=1,2…number ofreplication

Where, y_{ijk} = the response measures for the ijkth observations μ
= the overall mean effects
α_i = the effects of ith level of inflorescence removal β_j
= the effects of the jth level of earthing-up
$(\alpha\beta)_{ij}$ = the effects of the interaction effects between inflorescence removal and time of earthing-up, ϵ_{ijk} = the random error compared for the whole factor k = number of replicatio

4. RESULTS AND DISCUSSION

The effect of time of earthing-up and inflorescence removal was evaluated with respect to growth, yield and quality attributes of potato, and the results obtained are presented and accordingly discussed in light of the available literature here under.

4.1. Growth Parameters

4.1.1. Leaf area

Leaf area was very highly significantly (*$P<0.001$)* affected by the main effects of time of earthing-up and inflorescence removal. It was also significantly (*$P<0.05$*) influenced by the interaction of time of earthing-up and inflorescence removal (Table 3 below).

The largest leaf area (37 cm^2) was obtained from plants that received earthing-up at 15 days combined with inflorescence removal, followed by those that received earthing-up at 30 days (32.66 cm^2), while the lowest leaf area (23.90 cm^2) was obtained from the plants that have not received earthing-up and inflorescence removed (Table 4). The results of this experiment indicated that early earthing-up, combined with inflorescence removal, recorded the highest leaf area, whereas the lowest leaf area was obtained from delayed and no earthing-up treatments. In no earthing-up treatment, there could be lower soil aeration and soil colloids might have restricted root growth and this in turn resulted in the smaller leaf area. In contrast, earthing-up at 15 days after complete plant emergence might have supported the plants by creating improved soil aeration, a better root growth for nutrient absorption, and consequently increased plant growth and leaf area. The present result is in agreement with the finding of Qadir *et al*. (1999) who reported that plants which received earthing-up two weeks after complete plant emergence resulted in better yield and yield components of potato, including leaf area. Tesfaye *et al*. (2012), similarly, reported the widest leaf area when potato was earthed-up early.

Inflorescence removal avoids apical dominance, and this results in an increase of branching per plant, and in turn increase in leaf area. Removal of terminal buds creates higher total leaf area than those which didn't receive inflorescence removal treatment. This could be attributed to the observed high number of lateral branches and expanded leaves in response to pinching of the terminal buds. Removing terminal buds stimulated the growth of lateral branches along with the expanded leaves in potato. According to Robert and Dwelle (1990), when the inflorescence is removed the plants rapidly attained desired index of leaf area. Nasrollahzade *et al*. (2005) also reported an increased number of branches and photosynthetic area of the plant as a result of inflorescence removal.

Table 3. Interaction effect of time of earthing-up and inflorescence removal on leaf area

	Leaf area (cm^2)			
Inflorescence removal	Time of earthing up			
	0	15	30	45
Removed	23.90^d	37.00a	32.66^b	28.33^c
Not removed	24.00^d	31.33^b	27.83^C	25.00^d
LSD	1.62			
CV(5%)	2.95			

Values followed by the same letter within the column are not significantly different at 0.05% probability level.

4.1.2. Plant spread

The main effects of time of earthing-up and inflorescence removal highly significantly (P<0.01) affected plant spread. The interaction of time of earthing-up and inflorescence removal significantly *(P<0.05*) influenced plant spread (Table 4). The largest plant spread/canopy (64.83 cm) was recorded from earthing-up at 15 days after complete plant emergence combined with inflorescence removal, whereas the smallest plant spread (54.83 cm) was recorded at treatment combinations of no earthing-up and no inflorescence removal.

The results of this experiment indicated that early earthing-up combined with inflorescence removal recorded a wider plant spread. Earthing-up might have created a favorable environment for the root zone to take up nutrients supporting plants to attain a better growth. This result is in agreement with the work of Tesfaye *et al.* (2012) who reported that plants that received earthing-up at 15 days after complete plant emergence recorded the widest plant spread. Apical meristem tissue of aboveground parts, such as growing buds, flower buds and growing inflorescence on the stem are the main centers for auxin synthesis. Auxins have an effective role in apical dominance, and apical bud is a deterrent factor of side growth, and growth hormones, especially auxins can strongly control number of side stems. In conformity with the result of the present work, Sarmadnia and Koochaki (1993) reported an increase in the plant canopy as a result of flower removal. Lahooti *et al.* (2003), Nasrollahzade *et al.* (2003), Khajepoor (2004) and Nazari (2010) also reported an increase in the number of side branches, and canopy spread, as a result of inflorescence removal, which might be obtained through removing the apical dominance.

Table 4. Plant spread (canopy) as affected by the interaction of earthing-up times and inflorescence removal

Inflorescence removal	Plant spread			
	Time of earthing up			
	0	15	30	45
Removed	57.16^{c}	64.83^{a}	62.16^{b}	57.42c
Not removed	54.83^{de}	58.88^{c}	57.50^{c}	55,51^{de}
LSD %	1.87			
CV (5%)	5.40			

Values followed by the same letter within the column are not significantly different at 0.05% probability level.

4.1.3. Plant height

Plant height was highly significantly *($P<0.01$)* influenced by the main effect of time of earthing-up. However, it was not affected by inflorescence removal and the interaction of earthing-up and inflorescence removal. The highest plant height (87.63 cm) was recorded from the plants which received earthing-up at 15 days after complete plant emergence, followed by those earthed-up at 30 days (83.86 cm). The shortest plant height (79.5 cm) was observed from the plants which received earthing-up at 45 days, however, it was not statistically different from those with no earthing-up (Table 5). The difference in earthing-up could probably be due to the fact that managing (earthing-up) of the soil made the soil friable, and resources such as air, water, and nutrients easily available to plants. Early earthing-up facilitated the nutrient absorption through increased soil aeration, while the plants which didn't receive earthing-up, might have experienced stress to develop their vegetative growth. This work is in agreement with the finding of Tadele *et al.* (2016) who reported higher plant height when the potato plants received earthing-up two weeks after complete plant emergence.

4.1.4. Number of main stems/hill

Time of earthing-up highly significantly ($P<0.01$) affected the number of main stem per hill, but it was not significantly ($P>0.05$) influenced by inflorescence removal. Similarly, the interaction of time of earthing-up and inflorescence removal didn't affect this parameter (Appendix Table 4). The highest main stem number (4.03) was recorded at 15 days of earthing-up after plant emergence (Table 5). This value, however, was not statistically different from the number of main stems obtained from the plants which received earthing-up at 30 days. The lowest number of main stems per hill (3.52) was recorded from the plants which didn't receive earthing-up treatment, and this value was not statistically different from earthing-up at 45 days after complete plant emergence (3.59). This could be because early earthing-up might have created better aeration and provided suitable condition for the development of tubers. The result of current investigation is consistent with the finding of Majid and Roza (2001) who reported that earthing-up of potato plants when they reach to a height of 25 to 35 cm, gave a better vegetative growth and facilitated the underground growth and increased the number of stems. Similarly, Muhammad *et al.* (2013) also reported a minimum number of stems per plant when the potato plants were grown on unleveled land, followed by tubers planted in furrows without ridges.

Table 5. Effect of time of earthing-up and inflorescence removal on potato plant height, main stem number/hill and days to maturity.

Treatments	Plant height (cm)	Number of main Stem hill	Days to maturity
Time of earthing up			
0	79.59^{d}	3.52^{d}	114^{e}
15	87.35^{a}	4.03^{a}	118c
30	83.55^{b}	3.80^{b}	117^{d}
45	82.55^{c}	3.70^{de}	116^{d}
Inflorescence removal			
Removed	79.79^{c}	3.64^{c}	116^{d}
Not removed	79.59^{c}	3.52^{d}	114^{e}
LSD	0.95	0.21	1.27
CV%	1.33	3.23	0.80

Values followed by the same letter/s within the column are not significantly different at 0.05% probability level.

4.1.5. Days to 50 % maturity

Time of earthing-up and inflorescence removal highly significantly (*P<0.01*) affected days to maturity. However, this parameter was not affected by the interaction of the two factors. The longest days to maturity (118 days) was observed at 15th day earthing-up treatment, whereas the earliest days to maturity (114 days) was recorded from plants which didn't receive earthing-up (Table 5). The results of this experiment revealed that early earthing-up delays days to maturity as compared with the late and no earthing-up treatments. This could be because earthing-up at 15 days after complete plant emergence coincided with active growth stage of the potato plants, and this favorable environmental conditions might have created an extended vegetative growth and in turn delayed maturity. In contrast, the plants grown without earthing-up might have experienced a stress condition and tended to enter to reproductive phase earlier, rather than staying on vegetative phase. Result of the current investigation is in agreement with the finding of Qadir (1997) who stated that earthing up at 15 days after complete plant emergence resulted in a better plant performance. The number of days to reach maturity is the important parameter for potato producers in that, it enables the growers to develop a suitable production as well as a marketing plan (Khalafalla, 2001).

With regard to inflorescence removal, the longest days to maturity (116 days) was recorded when inflorescence was removed. The earliest days to maturity (114 days) were recorded in no inflorescence removal treatment (Table 5). The observed delay in maturity could be due to growth of side branches when inflorescences are removed, and this in turn extended vegetative growth of the potato plant. Nazari (2010) reported the longest days to maturity when potato inflorescence was removed.

4.1.6. Stem diametere

The main effects of earthing-up and inflorescence removal highly significantly ($P<0.01$) affected stem diameter. This parameter was also significantly ($P<0.05$) influenced by the interaction of time of earthing-up and inflorescence removal (Table 6). The largest stem diameter (7.96 cm) was obtained from earthing-up at 15 days combined with inflorescence removal, followed by earthing-up at 30 days after complete plant emergence and inflorescence removal (7.03 cm), whereas the smallest stem diameter (4.33 cm) was obtained from treatment combination of no earthing-up and no inflorescence removal. This could be because early earthing-up might have better controlled weeds, created a conducive environment for the plant to take up more nutrients, and consequently resulted in an increase in stem diameter. This result agrees with the work of Qadir *et al.* (1999) and Qadir (1997) who reported the highest stem diameter from the plants which received earthing-up at 15 days after complete plant emergence. This result is also consistent with that of Gebremedhin *et al.* (2008) who reported that one time earthing-up increased yield components of potato as compared to the one that has not received earthing-up.

When inflorescence is removed, growth of the apical buds is stopped and stem girth increased. Flowers compete for assimilates with stem and other plant parts and not removing them results in a weak stem. Sarmadnia and Koochaki (1993), Lahooti *et al*. (2003) and Khajepoor

(2004) reported an increase in side growth as a result of inflorescence removal, which avoids apical dominance in potato plants. Nasrollahzade *et al.* (2003) and Nazari (2010) also reported a significant increase in size of stem due to inflorescence removal.

Table 6. Potato stem diameter as affected by interaction effect of time of earthing up and inflorescence removal

Inflorescence removal	Stem diameter (cm)			
	Time of earthing up			
	0	15	30	45
Removed	6.40^{c}	7.95^{a}	7.03^{b}	5.86^{d}
Not removed	4.33^{f}	6.36^{c}	5.86^{d}	5.20^{e}
LSD	0.86			
CV (5%)	3.86			

Values followed by the same letter within the column are not significantly different at 0.05% probability level

4.2. Yield Parameters

4.2.1. Average tuber number/hill.

Average number of tubers was highly significantly *($P<0.01$)* affected by time of earthing up. This parameter was also significantly *($P<0.05$)* affected by inflorescence removal (Appendix Table 7). However, no significant ($P>0.05$) variation was observed for the interaction of time of earthing-up and inflorescence removal. The highest number of tubers/hill (12.06) was recorded at 15 days earthing-up, whereas the lowest number of tubers/hill (10.10) was obtained from no earthing-up treatment (Table 8). The result of the current investigation showed more tuber number in early earthing-up, while less number of tubers was recorded in late and no earthing-up treatments. Early earthing-up might have created favorable soil conditions for the formation and development of more number of tubers. This result is in agreement with the findings of Qadir, (1997) and Tesfaye *et al.* (2012), who reported significantly the highest number of tubers per plant at 15 days earthing-up after complete plant emergence. Similarly, Tafi *et al.* (2010) reported an increased number of tubers per plant when plants received earthing-up of about10 cm high

With regard to inflorescence removal, the highest number of potato tubers was recorded when inflorescence was removed. This might be because when the inflorescence is removed, the competition between flowers and tubers for assimilates will be reduced, and as a result more tubers are formed. This result is consistent with those of Tekalign and Hammes (2005) and Nazari (2010), who reported increased number of tubers per plant as a result of inflorescences removal.

Table 7. Effect of time of earthing-up and inflorescence removal on ATN/hill

Average tuber number				
Inflorescence removal	Time of earthing up			
	0	15	30	45
Removed	10	12.08[a]	11.84[bc]	11.43[b]
Not removed	10.62	12.06[a]	11.28[bc]	10.10[d]
LSD %	0.34			
CV (5%)	4.39			

Values followed by the same letter/s are not significantly different at 0.05% probability level.

4.2.2. Average tuber weight

Earthing-up and inflorescence removal highly significantly *($P<0.01$)* affected average tuber weight (g). This parameter is also significantly ($P<0.05$) affected by the interaction of time of earthing-up and inflorescence removal (Table 9). The highest average tuber weight (120.37 g) was obtained from the plants that received earthing-up at 15 days, combined with inflorescence removal, followed by earthing-up at 30 days, combined with inflorescence removal (111.83 g) (Table 9). Results of this experiment revealed that no earthing-up and delayed earthing-up, resulted in lower average tuber weights per hill. Early earthing-up probably increased the availability of nutrients and it may also have favored tubers to increase their size. On the contrary, no earthing-up might have caused soil compaction, which in turn, might have decreased availability of nutrients to the plants and consequently, resulted in a decreased mean tuber weight. The current finding is in agreement with the finding of Bohl (2010), who reported that earthing-up had significant effect on tuber number and average tuber weight per hill and tuber yield per hectare, and in all the cases the earthed-up plots gave the highest value compared to those which didn't receive earthing-up. Similarly, Girma *et al.* (2012) reported the highest tuber weight from the potatoes which received earthing-up as compared to those which didn't receive earthing-up. Stages of flowering and tuber formation and development in potato coincide, and this results in an intense competition between the two sinks for assimilates. Inflorescence removal can increase tuber weight because of removal of competitor for the assimilates. Faramarzi *et al*. (2011) reported that flower removal improved translocation of the assimilates to underground structures and increase tuber weight.

Table 8.Average tuber weight as affected by the interaction of time of earthing up and inflorescence removal

	Average tuber weight			
Inflorescence removal	Time of earthing-up			
	0	15	30	45
Removed	104.70^{c}	120.30^{a}	111.84^{b}	110.43^{b}
Not removed	103.50^{c}	110.91^{b}	108.90^{cb}	107.00^{cb}
LSD %	5.05			
CV (5%)	4.39			

Values followed by the same letter/s are not significantly different at 0.05% probability level

4.2.3. Marketable tuber yield

The data depicted in Table indicated that marketable tuber yield was highly significantly (*P<0.01*) affected by time of earthing-up. This parameter was also significantly (*P<0.05*) affected by inflorescence removal. Similarly, the interaction of time of earthing-up and inflorescence removal was also significant. The highest marketable tuber yield (34.40 ton/ha) was obtained from combination of earthing-up at 15 days and inflorescence removal, followed by earthing-up at 30 days and inflorescence removal (29.10 ton/ha), earthing-up at 45 days after complete plant emergence (28.54 ton/ha) and non earthing-up (24.03 ton/ha) (Table 11). This is in line with the work of Tesfaye *et al*. (2012) who reported that early earthing-up created better growth and development of the potato plants and this ultimately has resulted in increased marketable tuber yield. Inflorescence removing can increase marketable tuber yield through increasing tuber size. Nazari (2010) reported that removing inflorescence, increased potato marketable tuber yield up to 2.68 ton/ha (8.9%). Koucheki and Mahalati (1994) reported that flower development significantly affects the available assimilates due to changes in patterns of assimilate production and its allocation to the upper and underground plant.

Table 9. Marketable tuber yield of potato as affected by interaction effect of time of earthing-up and inflorescence removal

Inflorescence removal	Marketable tuber yield(ton/ha)			
	Time of earthing-up			
	0	15	30	45
Removed	24.03[d]	35.83[a]	29.10[b]	27.01[c]
Not removed	23.76[d]	29.01[cb]	27.50[cb]	27.20[c]
LSD %	1.60			
CV (5%)	3.51			

Values followed by the same letter are not significantly different at 0.05% probability level.

4.2.4. Unmarketable tuber yield

The ANOVA result showed that unmarketable tuber yield was highly significantly (*P < 0.01*) affected by time of earthing-up. This parameter, however, was not significantly (*P>0.05*) affected by inflorescence removal, and the interaction of time of earthing-up and inflorescence removal (Table 12). The highest unmarketable tuber yield (7.8 ton/ha) was recorded from no earthing-up treatment, followed by earthing-up 30 days after complete plant emergence (7.1 ton/ha), while the lowest unmarketable tuber yield (5.6 ton/ha) was recorded from no earthing-up and earthing-up at 15 days after complete plant emergence, respectively (Table 12). Results of this experiment revealed that the number of unmarketable tubers per plant decreased with early earthing-up. A delayed earthing-up practice and no earthing-up resulted in the highest percentage of green, deformed, insect attacked, and small sized tubers. This might be because of tubers grown without earthing-up are exposed to sun light, leading to tuber greening, making them unmarketable. In the absence of earthing-up, no favorable condition for the root system, resulting in small tubers which are considered as unmarketable. Earthing-up at late developmental stage of potato and no earthing-up might have exposed the potato tubers to stress, resulting in green and malformed tubers. This result is in agreement with the result of Qadir (1999) who reported that an increase in unmarketable tuber yield when potato plants not earthed-up.

Table 10. Unmarketable tuber yield as affected by time of earthing-up

Treatments	Unmarketable tuber weight(ton/ha)
Time of earthing up	
0	7.8^{a}
15	5.6^{d}
30	7.1^{b}
45	6.5^{c}
LSD 5 %	1.50
Inflorescence removal	
Removed	6.43^{b}
Not removed	6.33^{cb}
LSD 5%	1.50
CV%	10.36

Values followed by the same letter is not significantly different at 0.05% probability level

4.2.5. Total tuber yield

Total tuber yield was highly significantly *(P<0.01*) affected by time of earthing-up, and inflorescence removal. Similarly, the interaction between time of earthing-up and inflorescence removal was significant *(P<0.05)* (Table 13). The highest total tuber yield (41.66 ton/ha) was obtained from time of earthing-up at 15 days, combined with inflorescence removal, followed by earthing-up at 30 days, combined with inflorescence removal (37 ton/ha), and earthing-up 45 days after complete plant emergence and inflorescence removal. The lowest tuber yield (29.76 ton/ha) was recorded from no earthing-up and no inflorescence removal treatment (Table 13). Early earthing-up matches with active growth stage of the plant and this created favorable soil conditions for more expansion of roots, tuber initiation and development that increased tuber yield. The current investigation is in agreement with the report of Don and James (1990) showed that earthing-up at a later growth and development stage appeared not to give best tuber yield. Tesfaye *et al.* (2012) also reported early earthing-up treatments yielded higher tuber yield than the treatment that was not earthed-up. Pruning of flowers increases translocation of assimilates to the underground structures to increase the potato tuber yield. The competition of developing flowers with tubers for photosynthate is apparently a factor in determining final tuber yield. Inflorescence removal made an increase of 13% in tuber yield compared to the one without inflorescence removal. Nazari (2010) and Tekalign and Hammes (2005) reported tuber yield increase of 9 and 18 percent, respectively, when the inflorescence of potato was removed. According to reports of Almekinders and Struik (1996) and Framarzi (2011), flowers and tubers of potato compete to attract assimilates, and removing flower shifts assimilate transition to tubers.

Table 10. Total tuber yield as affected by the interaction of time of earthing up and inflorescence removal

Inflorescence removal	Total tuber yield(ton/ha)			
	Time of earthing up			
	0	15	30	45
Removed	31.96[d]	41.66[a]	37[b]	33.83[c]
Not removed	29.76[e]	36[b]	35.50[b]	32.83[dc]
LSD %	1.50			
CV (5%)	2.50			

Values followed by the same letter is not significantly different at 0.05% probability level

4.3. Quality Parameter

4.3.1. Number of green tuber

Time of earthing-up highly significantly (*P<0.01*) affected green tubernumber. However, this parameter was not affected by inflorescence removal and the interaction of time of earthing-up and inflorescence removal (Table 14). The highest number of green tubers 2.52 per plant was recorded from no earthing-up treatment while the lowest 1.47 was recorded from earthing-up at 15 days. The low green tuber number in early earthing-up could be due to that the newly formed tubers were covered by soil and were protected from direct sun contact. Result of Selman *et al.* (2008) reveal that, potato tuber exposure to direct sunlight in the field resulted in the development of a green pigment on the potato tuber. This result is in agreement with that of Pavek and Thornton (2009) and Majid and Roza (2011) who reported that the shallow-planted seed pieces of potato have yielded more green tubers due to positioning of tubers nearer to the sides of the potato hill.

Table 11. Green tuber number as affected by time of earthing-up

Treatments	Green tuber number
Time of earthing up	
0	2.52^{a}
15	1.47^{d}
30	1.99^{c}
45	2.05^{b}
LSD 5 %	0.55
CV%	8.53

4.3.2. Tuber dry matter

Dry matter content of tubers was not significantly influenced by time of earthing-up and inflorescence removal. Similarly, the interaction of time of earthing-up and inflorescence removal had no effect on dry matter content (Appendix Table 13). This may be because these traits are controlled by genetic factors rather than by agronomic practices such as inflorescence removal and time of earthing up. In this study only one variety (Belete) was used.

4.3.3. Tuber specific gravity

Time of earthing up and inflorescence removal did not affect tuber specific gravity. Similarly, this parameter was not affected by inflorescence removal. The tuber specific gravity recorded in all treatments of the current experiment are greater than 1.088. Based on specific gravity value, Fitzpatrick *et al.* (1964) categorized potato tubers as low (< 1.077), intermediate (1.077 ≤ X ≤ 1.086), and high (> 1.086) specific gravity grades. According to Kabira and Berga (2003), good quality potatoes should have a specific gravity value of more than 1.080. Potato tubers with specific gravity values less than 1.070 are generally unacceptable for processing. Time of earthing-up and inflorescence removal recorded high specific gravity of tubers which is between 1.11 to 1.13 g/cm^3. In this study, only one variety (Belete) was used, and specific gravity was not affected by time of earthing-up and inflorescence removal.

4.4. Correlation Analysis among Growth and Yield Components

The correlation analysis result indicated that plant spread, leaf area, average tuber number, average tuber weight, total tuber yield, marketable tuber yield and stem diameter had highly significant and positive correlation with days to maturity (Table 13). The result indicated that the above mentioned parameters can be increased by extending the days to maturity in which the plant can accumulate high dry matter at harvest for higher marketable and total tuber yield. Similarly highly significant and positive correlation was observed in plant spread with leaf area, tuber number, total yield, marketable yield and stem diameter which resulted in higher tuber yield of the potato plant.

The value of correlation coefficient indicated that tuber number was positively and highly significantly correlated with marketable and total tuber yield. This is in line with Nazari (2010) who reported that inflorescence removal increase number of tubers and consequently as a result it increased total tuber yield. Average tuber weight was also highly significantly correlated with marketable tuber yield and total tuber yield. Inflorescence removal from the apical potato plant results in less competition between flowers and potato tubers for assimilates, and this in turn increased tuber size and tuber weight. Tuber yield is the result of tuber weight and tuber size.

Hence, marketable and total tuber yield of potato can be increased by increasing the tuber number per unit area. On the other hand, number of green potatoes had highly significant and negative correlation with leaf area, tuber number, total yield, marketable yield and stem diameter which resulted in higher tuber yield of the potato plant. Therefore, the result of the correlation analysis indicated that the yield of potato tubers per hectare can be increased with increase in the above indicated parameters except number of green potato tubers.

Table 12.Correlation Analysis among Growth and Yield Components

	DM	PS	LA	ATN	ATW	TY	MY	SD	GT
DM	1.00	0.85**	0.92**	0.89**	0.89**	0.88**	0.79**	0.94**	-0.82**
PS		1.00	0.93**	0.95**	0.85**	0.96**	0.82**	0.90**	-0.69**
LA			1.00	0.99**	0.88**	0.87**	0.86**	0.88**	-0.77**
ATN				1.00	0.80**	0.94**	0.82**	0.90**	-0.80**
ATW					1.00	0.90**	0.88**	0.89**	-0.69**
TTY						1.00	0.90**	0.87**	-0.73**
MY							1.00	0.89**	-0.81**
SD								1.00	-0.77**
GT									1.00

*Correlation is significant at the 0.05 level. **Correlation is significant at the 0.01 level. DM=Days to Maturity, PS= Plant Spread, ATN Average Tuber Number, GT=Green Tuber. ATW=Average Tuber Weight, MTY=Marketable Tuber Yield, TTY=Total Tuber Yield,

5. SUMMARY AND CONCLUSION

Potato (*Solanum tuberosum* L.) is one of the most popular and widely cultivated vegetable crop in Ethiopia. It is the fastest growing staple food crop and source of cash income for small holder farmers. Earthing-up and inflorescence management plays an important role for increasing potato tuber production. Therefore, the present study was conducted to assess the effect of time of earthing up and inflorescence removal on yield and quality of potato at Jimma, Southwestern Ethiopia. The study was carried out between December 2016 and March 2017 under irrigation condition. "Belete" was a potato variety used for this study, and the experiment was set as a 2x4 factorial with four different earthing-up treatments (no earthing-up, earthing-up at 15 days, 30 days and 45 days after complete plant emergence), and two treatments of inflorescence removal (inflorescence removed and not removed) with three replications. Relevant data on growth, yield and quality parameters were collected and analyzed using SAS Version 9.3 statistical software.

The results indicated that a combined effect of time of earthing-up and inflorescence removal significantly influenced leaf area, plant spread, stem diameter, average tuber weight and total tuber yield. The interaction of earthing-up at15 days and inflorescence removal recorded the maximum leaf area (37.5 cm^2), the widest plant spread (64.83 cm), and the largest stem diameter (7.96 cm), whereas the treatments without earthing up and with no inflorescence removal, recorded the minimum leaf area (21.0 cm^2), the narrowest plant spread (54.83 cm), and smallest stem diameter (4.33 cm). The highest tuber weight (120 g), the largest marketable tuber yield (35 ton/ha) and the highest total tuber yield (41.66 ton/ha) were recorded from earthing-up at 15 days after complete plant emergence, whereas the treatments without earthing-up and with no inflorescence removal, recorded the minimum average tuber weight (103.5 g), the lowest marketable tuber yield (24.03 ton/ha) and the least total tuber yield (29.76 ton/ha).

Plant height and number of green tubers per plant were significantly affected by the time of earthing-up. The longest plant height (87.35 cm) and the lowest green tuber number (1.5) were recorded from earthing-up at 15 days after complete plant emergence. Days to maturity and average tuber number per plant were affected by time of earthing-up and inflorescence removal. The largest average tuber number per hill (12.06) and the longest days to maturity (122 days) were recorded from earthing-up at 15 days after complete plant emergence.

The results of the present study demonstrated that potato tuber yield is influenced by the different earthing-up times and inflorescence removal. Generally, the study revealed earthing-up at 15 days after complete plant emergence and inflorescence removal gave better plant growth, yield component and yield parameters.

Future Line of Work

Potato is one of the major food and cash crops in Ethiopia. Its production, however, is constrained by various factors, including lack of high yielding cultivars with a wider environmental adaptation, and limited use of improved agronomic practices, among others.

Variety, growing location and season are known to affect production and productivity of potato, therefore, it is suggested, future research, to address assessment of the effect of earthing-up and inflorescence removal, by involving more cultivars, different locations and seasons.

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7. APPENDICES

Appendix Table 1. Plant height

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	192	64.01	51.7	**
Inflorescence removal	1	0.1	0.01	0.02	ns
Earthing up*Infloremoval	3	0.66	0.28	0.23	ns

R-Square	Coeff.Var	PH mean
0.97	1.33	83.29

** highly significant, ns non significant, PH= plant heig ht

Appendix Table 2. Stem diameter

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	9.23	3.0	4.3	**
Inflorescence removal	1	15.79	15.79	3	*
Earthing up*Infremoval	3	4.84	1.61	2.6	**

R-Square	Coeff.Var	Root mean	SD mean
0.97	3.94	0.24	6.25

**and* highly significant and significant, SD= stem diamtere

Appendix Table 3. Number of main stem/hill

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	1.36	0.45	39.20	**
Inflorescence removal	1	0.04	0.04	3.66	ns
Earthing up*Infremoval	3	0.09	0.03	3.82	ns

R-Square	Coeff.Var	Root mean	Nms mean
0.90	2.84	0.10	3.79

** highly significant, ns non significant , NMS= numbe r of main stem

Appendix Table 4. Plant spread

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	140.19	48.73	76.70	**
Inflorescence removal	1	82.21	82.21	134.93	**
Earthing up*Infremoval	3	16.77	5.59	9.18	*

R-Square	Coeff.Var	Root mean	PS mean
0.96	3.87	0.78	58.54

**and* highly significant and significant. PS=plant spread

Appendix Table 5. Leaf Area

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	468.12	156.04	220.98	**
Inflorescence removal	1	111.37	111.37	157.72	**
Earthing up*Infremoval	3	9.9	3.33	4.72	*

R-Square	Coeff.Var	Root mean	LA mean
0.98	2.9	0.84	28.44

**and* highly significant and significant respectively LA=leaf area

Appendix Table 6. Days to maturity

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	94.79	31.59	62.45	** **
Inflorescence removal	1	57.04	57.04	112.74	ns
Earthing up*Infremoval	3	2.45	0.81	1.62	

R-Square	Coeff.Var	Root mean	DM mean
0.95	0.60	0.71	117.95

**and* highly significant and significant, ns=non significant, DM=days to maturity

Appendix Table 7. Average tuber number

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	26.65	8.88 1.22	17.71	** *
Inflorescence removal	1	1.22	3.82	2.45	ns
Earthing up*Infremoval	3	3.82		2.54	

R Square	Coeff.var	Root mean	ATN mean
0.82	6.25	0.70	11.71

**and* highly significant and significant, ns=non significant, ATN=average tuber number

Appendix Table 8. Average tuber weight

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	402.54	134.18	57	**
Inflorescence removal	1	111.28	11.28	47	**
Earthing up*Infremoval	3	56.93	18.97	8.16	*

R-Square	Coeff.Var	Root mean	ATW mean
0.95	4.39	1.52	109.70

**and* highly significant and significant, ATW= average tuber weight

Appendix Table 9. Marketable tuber yield.

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	220.66	73.55	75.21	**
Inflorescence removal	1	36.30	36.30	37.13	*
Earthing up*Infremoval	3	37.87	12.62	12.91	*

R-Square	Coeff.Var	Root mean	MTY mean
0.95	3.51	0.98	28.12

**and* highly significant and significant, MTY=marketable tuber yield

Appendix Table 10. Unmarketable tuber yield

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	34.00	11.33	19.10	*

Inflorescence removal	1	0.09	0.09	0.15	ns
Earthing up*Infremoval	3	0.065	0.21	0.37	ns

R-Square	Coeff.Var	Root mean	UMTY mean
0.82	10.36	0.77	7.43

*significant, ns= non significant, UMTY= unmarketable tuber yield

Appendix Table 11. Total tuber yield

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	215.94	71.98	86.19	**
Inflorescence removal	1	40.30	40.30	48.35	**
Earthing up*Infremoval	3	20.0	6.66	7.98	*

R-Square	Coeff.Var	Root mean	TTY mean
0.95	2.62	0.91	34.82

**and* highly significant and significant, TTY=total tuber yield

Appendix Table 12. Green tuber

Source of variatio	DF	SS	MS	F value	Pr>F
Earthing-up	3	4.41	1.47	75.61	**
Inflorescence removal	1	0.02	0.02	1.31	ns
Earthing up*Infremoval	3	0.14	0.04	2.49	ns

R-Square	Coeff.Var	Root mean	GT mean
0.94	7.04	0.13	1.98

** highly significant, ns=non significant, GT= green tuber number

Appendix Figure 1. Photo galleri of Inflorescence removal and measuring tuber weight

Appendix fig a. Inflorescence removal

Appendix Fig b. 50 % Maturity

Appendix fig c. Measuring fresh tuber weight