International Journal of Agriculture & Agribusiness
ISSN: 2391-3991, Volume 7 Issue 1, page 24 – 40
ISSN 2391-3991
Zambrut

International Journal of Zambrut
Research & Review
Proceeding & Conference
Thesis & Antithesis
Novelty & Findings
Sciences; Economics & Business; Social, Politics & Humanities; Law; Engineering & Industry; Biology, Physics & Matematics; Agriculture & Agribusiness; Health, Nursing, & Medicine; Informatics, Technology & Computers; Food & Nutrition

# Factors Affecting Potato (*Solanum tuberosum* L.) Tuber Seed Quality in Mid and Highlands: A Review

**Dejene Abera Guluma**

Dejene Abera Guluma
Oromia Agriculture &Natural Resource Bureau, Kimbibit Woreda Agriculture & Natural Resource Office
Sheno, Oromia, Ethiopia

***Abstract:*** *Potato (Solanum tuberosum L.) is one of the tuber crops grown in mid and highlands of Ethiopia as a high potential food security crop due to its high yield potential per hectare and nutritious tubers. It is also used as income generating commodity for farmers. Even though, the edaphic and climatic conditions are suitable for production of high quality potato in Ethiopia, the national average production is as low as 8 t ha-1. The low acreage and yield are attributed to many factors. However, one of most significant constraints to increasing productivity and overall production is the chronic shortage of good quality seed tubers. In Ethiopia, aspects of potato tuber seed quality like purity, genetic quality, health, size, physical damage and physiological age are serious problem because of varietal mix-up, poor storage mechanisms, prevalence of diseases and pests and poor knowledge of seed selection. Farmers use a potato tuber of inferior quality as a planting material which is less accepted by market to sell as a ware potato. This is because of scarcity of potato seed tuber produced by specialized seed growers and also lack of awareness of the farmer about the appropriate size of tubers which result with vigor plant stand as well as better final yield. In the production of potato, quality of seed potatoes is an important determinant of the yield and quality of the final product. Hence, to increase potato production and productivity calls for improvement of the quality of seed potato with in the country is very important. Therefore, this review briefly presents factors affecting potato tuber seed quality and their management in mid and highlands of Ethiopia.*

***Keywords:*** *Preharvest factors, postharvest factors, potato tuber seed & quality.*

## 1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the tuber crops grown in mid and highlands of Ethiopia as a high potential food security crop due to its high yield potential per hectare and nutritious tubers. It is also used as income generating commodity for farmers (Aliye *et al*., 2008). Its production in Ethiopia is possible on about 70% of the arable land (FAO, 2008; Medhin et al., 2000; Yilma, 1989). It is grown in four major areas of Ethiopia: the Central (highland areas of west and north shewa), the Eastern (highlands of East Harerge), and the North-Western (South Gonder, North Gonder, East Gojam, West Gojam and Agew Awi of Amhara region) and the Southern (Southern Nations, Nationalities and Peoples Regional State like Gurage, Gamo Goffa, Hadiya, Wolyta, Kambata, Siltie and Sidama) and partly in the Oromiya region (West Arsi zone)) part of Ethiopia (Hirpa *et al*., 2010).

These days potato is becoming a cash crop in Ethiopia and the introduction of improved varieties hasten the broadening of potato marketing, since seed potato create a better market price for the farmers than ware potato. However low quantity of production and lack of buyer are the major reasons for the farmers who did not sell potato (Agajie et al., 2007). As illustrated by Agajie et al. (2007), seed potato marketing in Ethiopia constrained by low market price and lack of buyers. Tuber deterioration during storage is among the factors affecting the quality thereby marketability of potato seed tuber. This shows the importance of post-harvest market quality maintenance since the quality and marketability of potato seed tuber not only determined by pre-harvest agronomic practices (Suttle, 2004).

Potato is a leading vegetable crop in Ethiopia and smallholder farmers cultivate about 50,000 ha each season (Getachew and Mela, 2000). Even though, the edaphic and climatic conditions are suitable for production of high quality potato in Ethiopia, the national average production is as low as 8 t ha-1 (Medhin *et al*., 2000). This national average yield is very low as compared to the potential yield (40 mg ha-1) obtained under research conditions (Getachew and Mela, 2000). Lack of quality seed potato (Amede *et al*., 2006; Hardy *et al*., 1995; Medhin *et al*., 2000), high yielding varieties and storage facilities coupled with poor agronomic practices (Medhin *et al*., 2000) have been found to contribute to the low yield of potato in Ethiopia. so that, the low acreage and yield are attributed to many factors (Lemaga *et al*., 1994; Endale *et al*., 2008a; Gildemacher *et al*., 2009a). However, one of most significant constraints to increasing productivity and overall production is the chronic shortage of good quality seed tubers. Seed systems can be defined in the way farmers produce, select, save and acquire seeds (Sthapit *et al*., 2008).

The quality of potato tuber seeds used as a planting material determines the quantity and quality of final product in potato production (Struik and Wiersema, 1999). According to Almekinders et al. (1994), farmers can get seed tuber from different sources such as own previous harvest, neighbor farmers, local market and formal seed sectors. A study by Fuglie (2007) on the priorities for potato research in developing countries including Ethiopia described that quality seed tuber availability gate higher priority rank by potato producing farmers in these countries. Furthermore, the problem of improved potato seed tuber availability and appropriate potato seed tuber management methods are severe for resource poor small-scale farmers.

Majority of potato farmers in east Africa use local seed tuber as a sources of seed due to unavailability of improved seed (Fuglie, 2007). According to Gildemacher *et al*. (2009) and Getachew and Mela (2000), about 50% of the potato farmers in this region including Ethiopia use farm saved potato seed tuber during planting. Moreover, the farmers in Ethiopia use a potato tuber of inferior quality as a planting material which is less accepted by market to sell as a ware potato (Getachew and Mela, 2000). This is because of scarcity of potato seed tuber produced by specialized seed growers and also lack of awareness of the farmer about the appropriate size of tubers which result with vigor plant stand as well as better final yield.

The fact that Ethiopia is a landlocked poor country facing negative trade balance makes the import of high-quality seed tubers from Europe or elsewhere very expensive (Hirpa *et al*., 2010a). Nevertheless, in the production of potato, the quality of seed potatoes is an important determinant of the yield and quality of the final product (Struik and Wiersema, 1999). Hence, to increase potato production and productivity calls for improvement of the quality of seed potato with in the country is very important. Perhaps, knowledge on the factor affecting the quality and current status of seed potato systems is essential for growers and other stakeholders. Therefore, the aim of this review is to present factors affecting potato tuber seed quality in mid and highlands of Ethiopia.

## 2. FACTORS AFFECTING POTATO TUBER SEED QUALITY

In Ethiopia, aspects of potato tuber seed quality like purity, genetic quality, health, size, physical damage and physiological age are serious problem because of varietal mix-up, poor storage mechanisms, prevalence of diseases and pests and poor knowledge of seed selection. According to Hirpa *et al*. (2010) seed tuber quality, can be defined as the ability of a seed tuber to produce a healthy, vigorous plant that produces a high yield of good quality within the time limits set by the growing season into which the seed is going to be used. Seed tuber quality is affected by seed health, physiological age and status, seed size, seed purity and genetic quality. In all potato growing areas of Ethiopia most farmers use seed potatoes of unknown origin. Farmers obtain their seed tubers usually from the local market if they do not set aside tubers from their own previous season production. Different varieties of potato are mixed during harvest or trade (Mulatu *et al*., 2005a). According to Guenthner (2006) investigation it was observed on seed potato markets in the central and northwestern areas of Ethiopia that traders mixed seed tubers purchased from different growers. In the southern area, the same practice was observed.

Among the Ethiopian smallholder farmers in all areas, it is Common practice to save tubers for seed that are too small and inferior to be sold for consumption (Mulatu *et al*., 2005a; Endale *et al*., 2008a; Gildemacher *et al*. 2007). Small-sized tubers may have two problems. The first one is delayed emergence and low sprout vigour and number because of low food reserve (Lommen 1994; Lommen and Struik 1994). The second is that they might be a progeny of an infected mother plant and thus infected by diseases, because infected mother plants usually give small tubers (Struik and Wiersema1999). In Ethiopia, the use of small potato tubers as seed might have contributed to the building up of high level of disease especially in the locally grown varieties. However, there are areas where many farmers use medium-sized tubers for seed. For instance, 72% of farmers in Degem district of north Shewa, 66% of farmers in Jeldu district of west Shewa in central area and 63% of the farmers in Banja district in northwestern area selected medium-sized tubers from the whole produce immediately after harvest, to save for seed. Also Gildemacher *et al*. (2009b) found that 40% of the potato farmers in the northwestern area of Ethiopia selected medium-sized tubers for seed.

### 2.1. Pre Harvest Factors

Postharvest management starts with pre-harvest managements. The quality of potato tuber seed is established in the field and can only be preserved during post-harvest. Abiotic factors influencing tuber maturity, cultivar- and season-variability have great impact on final quality (Driskill *et al*., 2007). Vine desiccation is another factor which strongly impacts quality; it triggers both maturation of the tuber periderm and stolon release, and in seed potato production it can also control tuber size. To manage all these variables a multifactorial approach is recommended to mitigate side effects which may affect quality (De Meulenaer *et al*., 2008). Pre harvest factors that affect the quality of potato seed tuber are discussed as follows:-

#### 2.1.1. Agronomic Practices

The aim of crop husbandry varies between seed and ware potato production system. High rate of multiplication, maintaining health and optimum physiological quality of seed tuber are the main focus in seed potato production whereas, in ware potato production system, high yield and disease control upto economic level as well as consumption and processing quality of tubers are given priority. However, the final quality and quantity of potato yield is determined by the quality of the potato seed tuber used at the time of planting (Struik and Wiersema, 1999). According to Fuglie (2007), availability of quality potato seed received higher priority by farmers in East Africa (Ethiopia, Kenya and Uganda). High quality of potato seed tuber could be achieved through the application of appropriate production practices which start from selecting best production site (Struik and Wiersema, 1999). Potato needs intensive management and production of better quality potato tuber demands timely application of the appropriate production inputs such as nutrients, water and crop protection measures. These packages of seed potato production are responsible to increase the developmental process throughout the life span of the potato crop (Pehrson et al., 2010).

**2.1.1.1. Soil preparation in seed potato production**

Potato crop production demands well prepared soil even than other crops, since expansion of tuber needs enough amount and optimum textured soil and also for ease of harvesting. Moreover, ploughing regulates soil temperature and the moisture level of the soil and the growth of sprout influenced positively as the soil temperature is warmer as far as the soil has adequate moisture level (Pavek and Thornton, 2009). According to Pavek and Thornton (2009), soil moisture content and temperature differences are the most common factors followed by volume and mechanical resistance of soils in affecting sprout growth. This is because, the emergence of potato crop limited by differences in temperature and moisture level of soil which shows the importance of this factors in potato production.

**2.1.1.2. Planting time and depth in seed potato production**

Once the soil preparation done, planning of appropriate planting time is important since the growing condition, which the crop faces afterwards, determined by the time of planting used (Struik and Wiersema, 1999). According to Struik and Wiersema (1999), earlier planting is preferable since this practice helps the crop to use all conducive environmental conditions of the production season potentially. Moreover, potato crop emergence impeded if planting is done when the soil environment is hot and cold and planting during the occurrence of these soil conditions (hot and cold) resulted with poor crop stand (Struik and Wiersema, 1999).

Appropriate planting depth is one of the main agronomic practices required for potato production, this is because, potato tuber is produced underground which is economical part of the crop. Early development below ground morphology, tuber expansion, yield and tuber quality are among the aspects affected by planting depth (Pavek and Thornton, 2009). Moreover, planting depth determines the time and energy the sprout requires to emerge, thereby early establishment and vigour are affected which are vital in seed potato production (Struik and Wiersema, 1999). For instance, deep planting may result in delayed ground cover. On the contrary, deeper planting help to overcome tuber greening, exposure of tuber to external environments, water shortage and to reach the expected yield (Pavek and Thornton, 2009). According to Pavek and Thornton (2009), planting potato in shallow depth results with declined marketable yield and gross income from potato crop production. This is because, in case of shallow planting depth, rapid sprout emergence restricted by less soil moisture content. Soil temperature also has its contribution towards hastening sprout emergence. Accordingly, warmer soil temperature positively affects the emergence as far as the moisture content of the soil is in adequate level. As explained by Pavek and Thornton (2009), more stem can be produced from pieces of seed which planted shallower, since shallower planting allows the pieces of seed to be exposed to warmer soil temperatures than deeper planted seed pieces.

An investigation by Pavek and Thornton (2009) reported that rapid sprouting used as a means against potato shoot and stem diseases resistance during the early stage of the potato crop and increases radiation capture efficiency early in the growing season thereby resulted in higher final tuber yield since higher radiation capturing efficiency in the early stage advance the vigour of the plant onwards and also contribute to the quantity and quality yield advantages. Pavek and Thornton (2009) also reported, increased planting depth resulted with delayed emergence, higher number of nodes, stolon and tuber number whereas, shallow planting hastened potato plant emergence. But this early emergence not always results in increased number of tubers or higher final yield per entire plant. Although, the differences in the planting depth resulted with differences in rate of emergence, it doesn't affect the total yield of the potato crop.

**2.1.1.3. Plant population/ spacing in seed potato production**

Potato crop needs to get enough intra and inter row spacing to allow maximum tillering of the plant as well as an optimum number and better quality tuber formation. In most of study, addressed potato producing areas of Ethiopia spacing of 20-30 and 60-75 cm are recommended between plants and between rows, respectively (Agajie et al., 2007). As indicated by Pavek and Thornton (2009), tuber expansion is one of the tuber development characteristics most affected by spacing among the other tuber development characteristics. This is because the surrounding soil volume becomes insufficient to hold the expanding masses of tubers in addition to competitions imposed by having crops planted near each other.

Gebre and Giorgis (2001) illustrated that, having optimum number of plants per unit area and spatial arrangements have a great potential in securing high potato tuber yield. This warrant the importance of practicing appropriate spacing in potato production and this becomes more important in seed potato production since to secure quality and quantity of the next season potato crop quality and healthy seed tuber is the most determinant in potato production. However, potato producing farmers in Ethiopia have less knowledge about the use of optimum spacing. This results from lack of awareness of farmers about the importance of using appropriate agronomic practices in potato production including-spacing. As reported by Gebre and Giorgis (2001), average tuber weight increased when wider spacing practiced while small sized tuber number increased in the case of narrower spacing.

According to Agajie et al. (2007), appropriate seed rate is crucial as far as potato productivity is considered, since low seed rate results in less yields, whereas seed rate more than research approved one result in more production cost since it hinders the application and ease of appropriate agronomic practices, demands more water, chemicals and fertilizer than the rate used in normal plant spacing per planted area. Moreover, more seed rate exposes each plant for inter and intra-row nutrient and radiation competition thereby result in less tuber formation per plant and small sized tuber production.

### 2.1.1.4. Water management in seed potato production

A potato crop is sensitive to water shortage. Hence, to meet the water requirement and reach with high quality and quantity of final potato tuber yield, efficient and effective water management is crucial (Pehrson et al., 2010). Potato production needs intensive management practices among which appropriate water management is the crucial one (Pehrson et al., 2010). According to Pehrson et al. (2010), most potato cultivars are characterized by their shallow rooting system and grown on soil type having low water holding capacity, since this kind of soil is preferable for the ease of potato tuber harvesting. This makes potato crop more susceptible to water stress than a lot of other crop species. Regular monitoring of soil moisture content, scheduled watering and having water resource and/or irrigation system capable of providing the required amount of water are the most important factors to address effective water management in potato production and thereby to achieve the desired quantity and quality potato tuber production (Pehrson et al., 2010). They indicated that, applying the amount of water which exceed the potato crop demand as well as providing the amount of water which is lower than the crop requirement resulted with quantity and quality loss of potato tuber. Moreover, maximum water application results in loss of nutrient and water to the environment. This indicates the importance of effective water management as far as yield with high quality and quantity of potato tuber, reduction of environmental impacts and maintaining the overall profit from potato crop is concerned. Although, most potato producing farmers in Ethiopia are dependent on rain water, some farmers produce potato by using irrigation as a water source based on accessibility of irrigation water as well as irrigable lands. Furthermore, the farmers who practice irrigation are able to produce three times per year.

### 2.1.1.5. Soil Management

Maintaining the fertility of the soil is one of the most important agronomic practices needed to be followed in potato production (Agajie et al., 2007; LeMonte et al., 2009). High nutrient demand on soil for good tuber quality requires high organic matter and nitrogen input (Nesbitt and Adl, 2014). Sustainable agricultural practices such as balanced fertilizer regimes improved not only tuber yield but also marketing quality of potato (e.g., tuber size) (Tan *et al*., 2016).According to LeMonte et al. (2009), reliable supply of recommended amount of fertilizer helps to optimize economics of crop production and minimizes environmental losses. Potato is particularly sensitive to a steady supply of nitrogen fertilizer (LeMonte et al., 2009). According to these studies, although potato needs appropriate supply of nitrogen for increased yield, production of tubers of bigger size and minimum internal-external tuber defect, excessive supply of nitrogen has its own negative effect.

According to Westermann and Kleinkopf (1985), to increase the nitrogen use efficiencies and also final tuber yield of potato plant within the limitations of climatic conditions, disease occurrence and variety related problems developing appropriate recommendations and also application of recommended rates based on the dry matter production and nitrogen uptake rates of the crop at each specific development stage of the crop is the crucial issue concerning nutrient management in potato crop production. This study indicates that practicing the recommendation hasten early growth rate and sustain maximum growth rate which thereby result in potential yield while higher application resulted in delayed potato tuber growth. Especially, nitrogen fertilizer not only hasten the growth rates of potato tuber, it also plays a major role in the production and maintenance of plant canopy which result in continued tuber growth for a long growing period (LeMonte et al., 2009) and the nitrogen fertilizer demands of the potato crop varies between different growing stages which is relatively high during the periods of high tuber growth rates which warrants the importance of split application of nitrogen.

As demonstrated on a study of Agajie et al. (2007), about 94% of potato farmers in most potato producing areas of Ethiopia practice application of fertilizer of organic or inorganic sources. As indicated in the same study to get better tuber yield from potato crop, application of inorganic fertilizer during planting is recommended. Fertilizer application rate of 195 kg ha-1 DAP and 165 kg ha-1 urea are recommended by research for major potato producing area of Ethiopia and application of DAP is largely practiced by most potato producing farmers in the country (Agajie et al., 2007). According to Agajie et al. (2007), farmers who do not able to get the recommended amount of inorganic fertilizer, additionally apply organic fertilizer (compost and Farm Yard Manure (FYM)) to compensate the fertilizer demand of the potato crop and application of organic fertilizer also contributed to the reduction of production cost. But the knowledge on preparation and use of compost are in infant stage. While, application of manure is limited based on the distance of the farm from the village and its less availability, since this-days the number of cattle reared by individual farmer is dropping down due to scarcity of grazing land. Crop rotation is also an alternative means on which potato producing farmers depend to maintain and improve soil fertility. According to Agajie et al. (2007), potato producing farmers in Ethiopia practice crop rotation to maintain and improve the fertility of the soil in addition to the use of organic and inorganic fertilizer sources.

### 2.1.2. Climatic factors

Climatic factors influence the production of potato by affecting three phenological phases (Kooman et al., 1996) during preharvest. Initially, dry matter is divided between stems and leaves (growth stage II). In the second phase, which starts at tuber initiation, an increasing amount of accumulated dry matter is allocated to the tubers and a decreasing fraction to the leaves (growth stages III and IV). In the third phase all assimilates are allocated to the tubers (growth stage V). Leaf growth stops and photosynthesis eventually stops because of leaf senescence. The duration of the first phase, comprising the development period between emergence and tuber initiation, is shortened by short days and temperatures less than 20$^{o}$C. Tuber initiation is slower at temperatures over 20$^{o}$C. The duration of the second phase is affected by temperature with an optimum between 16 and 18$^{o}$C (van Heemst, 1986) or 14 and 22$^{o}$C (Ingram and McCloud, 1984) and by solar radiation. Crop senescence is shortened by high temperatures, especially greater than 30$^{o}$C (Midmore, 1990). The effects of agro climatological factors on physiological parameters of potato will be discussed below. Air Temperature, Solar Radiation and Photoperiod Due to the interactive effects of air temperature, photoperiod (day-length), solar radiation, and cultivar on the tuberization stimulus, these meteorological variables will be discussed together with emphasis on physiological responses to one or another climatic element consistent with the specific objectives of each research project.

The review by Haverkort (1990) points out that potato is best adapted to cool climates such as tropical highlands with mean daily temperatures between 15 and 18$^{o}$C as encountered in its center of origin. Higher temperatures favor foliar development and retard tuberization. Climatic conditions, as affected not only by the latitude but also by altitude, influence potato plant growth and development. Moreno (1985) found that plants grown at low (coastal) altitudes have low yield of tubers per plant as compared with those grown in the Andean highlands. Haverkort (1990) reports that an inconvenience of the short day sensitivity of the potato is that cultivars that make use of the whole growing season and produce well in northern Europe (5-6 month growing season), may mature too early and senesce between 60 and 70 days after planting in the equatorial highlands and consequently yield less. Cultivars that perform well at low latitudes in a 3to 4 month growing season start tuberizing late and mature too late at 50$^{o}$N.

Sarquis et al. (1996) stated that the magnitude of the effect of elevated temperatures on potato growth and final yield is determined by an intricate interaction between soil temperature, air temperature, solar radiation and photoperiod duration. Their data extended previous observations of reduction in photosynthesis rate under elevated temperatures. Under field conditions they concluded that reduced carbon assimilation rate could not explain the yield reduction observed; the temperature effect on assimilation was not as dramatic as it was on growth or yield. Other workers have reported a severe reduction in the rate of assimilation at air temperatures above 30°C under controlled experimental conditions. In such cases, the reduction in carbon assimilation rate was shown to correlate well with reductions in growth and yield (Ku et al., 1977; Midmore and Prange, 1992). These contrasting results reveal the complexity of plant responses to the combined effects of water and temperature stress, which inevitably occur in association under field conditions.

Although high temperature stress is a major uncontrolled factor affecting growth, development and productivity of plants, relatively little is known about genetic diversity for heat tolerance in potatoes. Tolerance to heat stress may involve many complex relationships. An adapted genotype must have a diverse and complex combination of genes for tolerance to high temperatures and for superior performance in the field (Tai et al., 1994). Potato cultivars and clones vary significantly in their ability to tuberize at elevated air temperatures and continuous irradiance. Tibbitts et al. (1992) carried out two experiments under controlled environments to determine the capability of 24 highly productive potato genotypes to tolerate continuous light and high temperature.

Gawronska and Dwelle (1989) studied the effect of high light levels and shaded low light levels on potato plant growth, biomass accumulation and its distribution. They observed that plants under low light did not produce auxillary shoots, while those under high light did. Tubers of plants under low light were very small and irregular in shape. In addition, at all growth stages, the percentage of biomass partitioned to the tubers was higher under high light than under low light conditions. According to Gawronska et al. (1990), potato plants grown under low light generally had lower rates of photosynthesis. Some clones maintained the higher rates of photosynthesis than Russet Burbank at nearly all-light levels, demonstrating the potential to breed for cultivars that maintain higher rates of photosynthesis and potentially higher tuber yields.

**Soil Temperature and Its Management**

The rate of development of sprouts from planted seed pieces depends on soil temperature. Very little sprout elongation occurs at 6°C. Elongation is slow at 9°C and is maximized at about 18°C. The time between planting and emergence depends on soil temperature. Field experiments carried out by Sale (1979) showed that emergence was linearly related to mean soil temperature and relatively independent of diurnal fluctuations up to an optimum of 22-24°C. Up to this optimum emergence could be considered as a degree-day requirement calculated either from soil temperature at tuber depth or air temperature. At temperatures above the optimum, emergence was inhibited. Little research is available on the effect of soil temperature during tuber growth on potato grade and quality. Kincaid et al. (1993), assessing the influence of the interaction between water management and soil temperature on potato quality in the Pacific Northwest, observed that the critical period for tuber quality appears to be from mid-June to mid-July, based on measured soil temperature differences, frequent sprinkler irrigation reduced soil temperatures, along with the incidence of sugar-end tubers.

Management practices, such as planting population density, use of mulch and irrigation might substantially modify the soil temperature regime within the root zone in such a way as to affect stolonization, tuber initiation and bulking, and tuber enlargement at a given site, particularly where solar irradiance availability is shown to be a non-limiting factor for potato production. Increase of plant population through a reduction of between-row spacing was effective in raising tuber yields in the hot tropics, largely through the increase in amounts of intercepted solar radiation, which can result about a significant decline on soil temperatures during the tuber growth. Since the proportion of marketable tubers was scarcely affected by planting densities, Midmore (1988) reasoned that potato plant population in hot climates should be as high as possible without limiting the amount of soil available for hilling-up.

In order to quantify the effects of organic mulch on soil temperature and soil moisture regimes during the growth of potato, Midmore et al. (1986a) conducted seven experiments at three contrasting hot tropical sites and reported that mulch retained more heat in the soil at night when combined with agronomic practices that themselves increased soil heat retention at. According to these authors mulch is more effective in cooling dry soils, especially at high irradiance. Heat retention at night following days of low irradiance was greater in mulched plots, whereas at high irradiance heat retention of mulched plots was intermediate between those of moist and drier control plots. Midmore et al. (1986b) showed that mulch increased tuber yield by 20% during the summer in Lima, Peru. Manrique and Meyer (1984), studying the impact of mulches on potato production during winter and summer seasons at the same site, found no effect on yields during the winter, but yield increases of 58% and improvements in soil moisture retention were obtained in the summer with surface mulch.

**Atmospheric Humidity and Wind, Wind Management**

There are very few recent studies dealing with the direct effects of relative humidity (RH) on potato growth, tuber yield and grade. Most of the contributions related to the influence of RH on potato refer to potato storage where RH is an important factor in tuber weight loss and the occurrence and severity of diseases and pests. The same scarcity of research exists with regard to the wind regimes at a particular location as an agro meteorological factor affecting potato production systems. Wheeler et al. (1989) studied the effect of two RH levels, 50% and 85%, on the physiological responses of three cultivars of potato (Russet Burbank, Norland, and Denali) in controlled-environment rooms under continuous light intensity at 20$^{o}$C. No significant differences in total plant dry weight were measured between the atmospheric humidity treatments, but plants grown under 85% RH produced higher tuber yields. Leaf areas were greater under 50% RH and leaves tended to be larger and darker green under drier than at more humid atmospheric conditions. The elevated humidity appeared to shift the allocation pattern of photosynthates to favor allocation to the tubers over leaves and stems.

Wind has important effects on potato. Pavlista (2002) reported that leaves injured by lower wind speeds show bronzed areas, brown with a shiny surface, due to the rubbing of leaves against each other. The bronzed areas tend to brittle from drying. When pressed the bronzed areas crack, forming a sharp-edged rip through the affected tissue. Under higher wind speeds, leaves not only bronze but also tatter. Tattered leaves typically have a 6 to 25 mm sized tears with irregular brownish borders. Stems may also be affected by winds. When exposed to a mild wind, stems may just be flopped around causing a slight weakness of the tissues. Under strong winds, vines might actually get twisted, bringing about a break or hinge-like weakness in the stems. If exposed to strong winds for several hours, the vine may twist all the way around and cause the stem to collapse, cutting off nutrient flow through the phloem between the vine and the tubers.

Wind also affects transpiration rates and, therefore, photosynthetic activity and crop yield. At sites where winds are frequently strong throughout the year, increased stomatal resistance can cause reduction in potato yield (Pavlista, 2002; Sun and Dickinson, 1997). At such sites, guidelines for the sustainable management of potato cropping systems need an emphasis on windbreak development including height, porosity, and orientation.

The optimum range of porosity for windbreaks is between 40 and 50% (Marshal, 1967). Windbreaks increased potato plant growth in height and leaf number, however, had limited effects on leaf length and width. Potato plants grown close to windbreaks yielded more than those grown at the furthest positions, with the highest production removed 3 times the windbreak height. Windbreaks increased potato yield by up to 7.7%, whereas Sturrock (1981) found windbreaks increased yield by 35%.

### 2.1.3. Genetic factors

The appropriateness of the variety or genetic quality of the seed is the adaptability to specific growing conditions and biotic or abiotic stresses and its food and processing quality characteristics (Hirpa *et al*., 2010). Growers have the choice of selecting preferred cultivars prior to planting crop. This choice may be limited by availability of planting material depending on the crop. In potato, a great deal of plant breeding has been done to provide a wide range of Varieties with different quality attribute. This can be seen in the wide range potato varieties available to growers for planting. Shapes, sizes, productivity levels, dry matter and taste attributes vary, as well as the ripening times and rates and postharvest longevity (Hewett, E.W. 2006). Potato variety improvement research has been undertaken in Ethiopia since 1975 with the objective of developing high-yielding, late-blight resistant and widely adaptable varieties. To this end many improved varities which are adaptable to altitudes ranging from 1000 to 3200 m and receiving 750–1500 mm rainfall with on farm high yielding ability were released (Gebremedhin *et al*. 2008). According to Endale *et al*. (2008b), improved potato varieties, namely Digemegn, Zengena, Jalene, Gorebella, Guassa, Menagesha, Tolcha and Wechecha, had an acceptable dry matter concentration and specific gravity for processing.

Farmers can produce relatively healthy seed potatoes by planting on appropriate planting dates, by applying positive selection, by allotting separate, better-quality, isolated plots to seed production and by timely haulm destruction. There are efforts underway to produce healthy seed potatoes by farmers in some parts of Ethiopia even though they are limited. In the central area of Ethiopia farmers commonly destroy the haulm of the part of their potato field reserved for seed. Thirty nine to fifty four per cent of the farmers in the central area of Ethiopia had adopted the recommended haulm destruction date. According to Endale *et al*. (2008a) and Gebremedhin *et al*. (2008), disease and insect pressures in the highlands, especially late-blight pressure, was considerably reduced because of the use of disease-resistant varieties. Farmers also renew their seed stock. According to Gildemacher *et al*.(2009a, b), 44% of farmers in the central and northwestern areas of Ethiopia renew seed on average every three seasons, but only 15% of their seed stock each time.

The improvement in the practices to produce better quality seed potato in the central area of Ethiopia is achieved because of the concerted efforts of the Ethiopia Institute of Agricultural Research (EIAR). Holeta Agricultural Research Centre of the EIAR has been assisting farmers in the central area of Ethiopia in providing seed and training through its farmers' research group (FRG) and farmers'field school (FFS). Because of the use of home saved seed, use of seed potatoes of unknown origin from local markets, limited use of resistant varieties, poor storage practices like leaving potato underground un-harvested and only limited adoption of haulm killing and selection practices by farmers, the seed tubers used by most potato producers cannot be healthy. However, according to Endale *et al*. (2008a) and Gebremedhin *et al*. (2008), in the highland areas, disease and insect pressures, especially late-blight pressure, were considerably reduced because of the use of disease-resistant varieties.

**2.1.4. Disease**

Late blight [Phytophthora infestans] is common in all potato growing areas of Ethiopia. In many parts of the country it is the cause for the shift of potato production from the long rainy season (meher) to off-season production, despite the high potential yield in the long rainy season (Bekele and Eshetu, 2008). According to Bekele and Eshetu (2008), local varieties do not cope with the disease pressure in the main rainy season and often are wiped out, particularly in the highlands. When seed tubers become infected by Phytophthora infestans they may rot during storage or will fail to produce emerging and surviving plants. Viruses [e.g., Potato leaf roll virus (PLRV) and Potato virus Y (PVY)] and bacterial wilt (Ralstonia solanacearum) are causing potato plant and tuber degeneration in Ethiopia. A study by Aliye et al. (2008) in Ethiopia on bacterial wilt finds out that disease are one of the most important factors that contributes to this high yield gap in the country. The prevalence of these diseases is high in the low to medium altitudes (Bekele and Eshetu, 2008). On a seed degeneration experiment undertaken in Holeta Agricultural Research Centre from 1997 to 2000, percent yield reductions due to viruses (mainly PLRV and PVY) were recorded of 62, 45, 44 and 41 in the varieties Tolcha, Genet, AL-624 and Awash, respectively (Bekele and Eshetu, 2008). Because these pathogens attack the foliage, root system and tubers, they are important throughout the crop cycle. Potato tuber moth, PTM (Phthorimaea operculella) is affecting seed potatoes in the field and stored in DLS (Bayeh *et al*., 2008).

Practicing appropriate crop protection methods are also the other important component of potato production packages to achieve a desired potato seed tuber yield and the overall benefit from the potato production. According to Haverkort et al. (2009), potato crop is affected by different diseases and pests of which late blight is the most damaging disease in the world. Furthermore, potato productivity hindered by late blight infestation throughout the developing countries and the problem takes the first rank among the other potato production and productivity limiting factors (Fuglie, 2007). As described by Haverkort et al. (2009), the serious damage caused by late blight also continued throughout the potato growing areas of the world and frequent pesticide application is considered the only possible means of late blight control. In Ethiopia also, late blight is the main problem in potato production and most of the potato producing farmers in the country faced this problem although the degree of infestation varies area to area (Agajie et al., 2007). According to Agajie et al. (2007), the incidence of late blight aggravated by presence of high rain fall, moisture and mist during the production season.

The use of fungicide is a common and compulsory practice for potato producing farmers in Ethiopia to overcome late blight problem and secure attainable yield but still some farmers are not aware of the importance of fungicide application to control late blight and the chemicals also not available in their local market and the price of the chemicals are expensive. In some potato producing areas of Ethiopia the farmers had forced to stop potato production due to late blight problems and since introduction of new late blight resistance varieties, these farmers re-started producing potato crop (Agajie et al., 2007). According to Sileshi and Teriessa (2001), field infestation per se causes about 9% potato yield loss out of the total potato tuber yield in Eastern Ethiopia. Moreover, the loss is pronounced in case of delayed harvest. In addition, field infestation increases the severity of potato loss during storage. Similarly, Medhin et al. (2000) reported upto 100% yield loss due to late blight. A study by Sileshi and Teriessa (2001) in the Eastern Ethiopia demonstrated that the degree of damage on potato tuber varies from cultivar to cultivar. In field as well as in store tuber infestation, results with multidimensional negative effect on farmers like; price reduction due to damaged tuber, less appropriateness to use as a planting material and increasing the cost spent for handling and tuber discards.

### 2.2 Post-Harvest Factors

After harvest, tuber quality management aims to delay dormancy break and limit weight loss and sweetening of potatoes. Senescent sweetening is a natural process that occurs as a result of tuber aging; it is irreversible and involves cellular breakdown. Low levels of reducing sugars are preferred in processing potatoes since when tubers are cooked at high temperatures (>120◦C) the Maillard reaction can occur. However this type of sweetening can be prevented with a single application (24 h) of 1-methylcyclopropene (1-MCP) prior to early and late ethylene supplementation (Foukaraki *et al*., 2016a). The impact of CO2, another storage extension gas, on frying quality is less clear. Studies on processing potato varieties showed negative effects on fry color when ethylene and $CO_2$ were applied together. Despite this, cultivar, gas concentration and timing, anseasonality strongly affect responses of tubers to $CO_2$ treatment.

#### 2.2.1. Maturity Stage at Harvest and Time of Harvesting

There are problems in timing of the harvest because of differences in maturity between plants. Mature tubers are more desirable for processing and storage than immature ones. Effects of physiological age on yield are of paramount importance for a country like Ethiopia where there is more than one potato production cycle per year, very poor seed tuber handling and poor storage conditions (Struik and Wiersema, 1999; Endale *et al*., 2008b). Multiple season production has two physiology related problems, a short time gap (limited time for a seed tuber to break dormancy) between adjacent seasons and a long time gap (resulting in physiologically old seed with reduced vigor) between un-adjacent seasons. According to Endale *et al*. (2008a) farmers in the district Shashemene, West Arsi zone, in the southern area of Oromia regional state, abandoned production of the improved variety Genet despite its good yielding ability compared to other varieties, because of the short dormancy period (less than 52 days) whereas the period between the off-season (January to March) and the meher season (June to September) is about 2 months and the period between two successive seasons of the same type is 8 months. In order for the potatoes to achieve optimal maturity and reach good dry matter levels harvest should be left as long as possible, bearing in mind the comments made on time of planting and the growth period.

#### 2.2.2. Post-Harvest Handling

In Ethiopia potato tubers are harvested, stored, packaged and transported with little care to prevent Physical damage to the tuber, most likely because of the low level of knowledge about the consequence of physical damage by all parties involved. Physical damage includes cuts, bruises and holes, inflicted on tubers during harvesting, storage, packaging and transportation. In a study undertaken on seed potato tubers stored on farm by using a traditional storage method, in two districts of the eastern area, Kersa and Alemay, 8% of the tubers were found to be damaged during harvest (Mulatu *et al*. 2005a).The tools used by farmers to dig out tubers from the soil might not be appropriate (too sharp or elongated ending). Physical damage in seed tubers may also occur during storage because of piling of one sack upon the other and lack of ventilation. Potatoes are usually packed in sacks which cannot protect tubers from any external pressure causing bruising and stabbing. Potato sacks are usually transported by pack animals and are tied by ropes on their back, which may cause bruising to tubers. Distant transportation takes place by Lorries. In this case loading and unloading is done by throwing up and down the tuber sacks. The seed tubers may be loaded with other sharp or beneath heavy materials which might cause damage to the tubers.

### 2.2.3. Potato Storage

Proper storage is one of the most important post-harvest criteria that must be met in order to ensure the quality of potatoes. Seed potato storage is a common practice in all potato producing areas of Ethiopia. Farmers store seed potato by leaving the tubers in the soil un-harvested (postponed harvesting); by other traditional storage methods like in a local granary, on bed-like structures or the floor in their house; or by diffused-light storage (DLS) (Hirpa *et al*., 2010). Because of storage and other post-harvest problems Ethiopia loses 30– 50% of its potato production (Endale et al., 2008b).Types of storage are described in more detail below.

### I. Postponed harvesting as storage mechanism

Postponed harvesting is the most commonly used storage method for potatoes in the highland and northwestern areas of the country to extend piece-meal consumption and also to wait for a better price (Endale et al.2008b). According to these authors, tubers can be kept up to 4 months without major quality loss in cool highlands. This storage method is also used to store seed potatoes. The investigation by Hirpa *et al*. (2010) revealed that about 37% of the farmers in Banja in the northwestern area of Ethiopia left the potato tubers for seed un-harvested in the field, whereas only 1% (Jeldu) to 3% (Degem) of the farmers in the central area used this method. In a study undertaken in the central and northwestern areas of Ethiopia, Gildemacher et al. (2009b) found that 47% of the potato farmers leave seed potatoes in the soil unharvested. This storage method was not reported in seed potato studies in the eastern and southern areas of Ethiopia. Postponed harvesting as storage mechanism has been creating problems in potato production for it could allow more accumulation of tuber-borne diseases than early harvesting (Endale et al.2008a). In ground storage of potato is also associated with large losses: in the Gojam and Gonder areas of the northwest losses of up to 50% have been reported caused by tuber moth and ants (Tesfaye et al.2008).

### II. Other traditional storage methods

Farmers also store seed potatoes in bags stacked on the floor in untidy places in the house where there is no ventilation, heaped loosely or put on a bed-like structure. Forty seven per cent of the farmers in the Degem district and 46% of the farmers in Jeldu district in the central area of Ethiopia (Hirpa *et al*, .2010) and 73.6% in the eastern area of Ethiopia (Mulatu et al.2005a) used bags to store their seed potatoes. About 45% of the potato farmers of Jeldu district in the central area of Ethiopia and 21% of the farmers of Banja district in the northwestern area of Ethiopia heap their seed potatoes loosely while 33% of the farmers of Banja district in the northwestern area of the country use a bed-like structure (Hirpa *et al*, .2010). Mulatu *et al*. (2005a) also found that about 26.4% of the farmers in the eastern area of Ethiopia piled up their seed potatoes in an open place or in a corner of their house. However, there are also farmers who store their potatoes in a better place. In the central and northwestern areas of Ethiopia, about 18% of the farmers use light spaces in the house to store their seed potatoes (Gildemacher *et al*.2009b). In the southern area farmers store seed potatoes in their home or in a store constructed for this purpose. Seed and ware potatoes are stored side by side in the same store or home. In the Shashemene district farmers cover stored ware and seed tubers with teff straw to protect the tubers from sun light. They use a thicker cover for the seed than for the ware. The farmers increase the thickness of the seed tuber cover a few weeks before planting. The farmers believe that an increase in the thickness of the cover will help the seed tubers to break dormancy and thereby encourage sprouting.

### III. Diffused light storage

Diffused light storage (DLS) is a storage method using a low cost rustic structure to store seed tubers. This type of storage maintains seed tuber quality by allowing diffusion of light and free ventilation which suppress sprout elongation and thereby slow-down aging of the sprout. In an experiment carried out in Holeta to quantify the effects of storage methods, Lemaga *et al*. (1994) found that seed tubers stored in multilayered burlap sacks (similar to farmers' dark storage method) produced significantly taller sprouts and lost significantly more weight than those stored in diffused light storage. This shows that diffused light storage has a better potential to keep quality seed tubers than the traditional storage method. Although the storage performance differs from variety to variety, seed potatoes can be stored in diffused light storage up to 7 months without considerable depreciation of seed quality (Endale *et al*., 2008b). The diffused light storage is usually used for the storage of seed potatoes of improved varieties whereas the other storage mechanisms are used for the storage of seed potatoes of local varieties. The reason for this might be that farmers are not aware of the importance of diffused light storage for the storage of local varieties (Hirpa *et al*., 2010).

In the central and northwestern areas of Ethiopia only 5% of potato farmers were found to use diffused light storage (Gildemacher *et al*., 2009b) but the use of diffused light storage for seed tubers of improved varieties is becoming common in the central area of Ethiopia. About 87% of the farmers in the central area and 25% in the northwestern area were found to use diffused light storage for storage of seed potatoes of improved varieties (Tesfaye *et al*., 2008). The use of diffused light storage is slowly increasing in the northwest. In the eastern area of Ethiopia, the use of diffused light storage is restricted to the cooperative community based seed enterprises established by the FAO seed security project (Mulatu *et al*., 2005a). For the southern area of the country there is no literature on the storage methods. The reason for not using diffused light storage, for about 22% of the farmers in the central area of Ethiopia and about 71% of the farmers in the north western area of Ethiopia was lack of awareness. Seed tubers stored in diffused light storage systems may become infected or infested with tuber moths, aphids, late blight or bacterial wilt; the use of insect screens can keep insects out, but not the pathogens (Hirpa *et al*., 2010).

#### 2.2.3.1. Storage Conditions

**Temperature**:-Correct storage conditions are crucial for production of potato. Cold storage is commonly used to control sprouting, yet temperature management depends on the intended market (Driskill *et al*., 2007). Cold-induced sweetening, however, does not only depend on post-harvest storage conditions but also on potato variety (Elmore *et al*., 2016) and growing location (Muttucumaru et al., 2017). Optimal holding temperatures for potatoes in storage depend on the potato variety and the intended end use of the product. Potatoes intended for seed are usually stored at 3 to $4^0$C (H.Kibar, 2012).

**Relative Humidity (R.H)** :- Maintaining high relative humidity in potato storage prevents some of the early season tuber dehydration and helps control the total shrinkage loss during the season. Shrinkage loss in storage is directly proportional to the length of the storage season and inversely proportional to the relative humidity conditions maintained within that storage. Free moisture is one of the most common problems traced to rot organism spread in storage. Condensation can become a problem when it occurs directly on the tubers or on any inside surface of the storage. Maintaining circulation air slightly cooler than the bottom of the pile will help prevent condensation directly onto the tubers. Likewise, condensation on building surfaces can be minimized by providing adequate insulation and making sure there is enough air movement to keep surfaces warm and to evaporate the moisture that collects before it drips onto the potatoes (H.Kibar, 2012).

**Light**:-Potato tuber accumulates chlorophyll when exposed to light, which turns the tuber green. The longer the tuber is exposed to light, the more greening will occur. The process will not reverse- the green color will not go away- if you then store the potato in a dark place. green potatoes can form compounds called glycoalkaloids that develop along with chlorophyll formation. Glycoalkaloids may make the potatoes taste bitter. In addition, glycoalkaloids are potentially toxic if you eat a lot of green potatoes at one time (H.Kibar, 2012).

**Carbon dioxide ($CO_2$) and oxygen ($O_2$)**:-The quality of many fruit and vegetable crops is enhanced if stored under high levels of $CO_2$ combined with low oxygen. This is not the case with potatoes, increased levels of carbon dioxide can be detrimental, promoting sprouting and effectively shortening storage life. Even the small amount of $CO_2$ produced as the potatoes respire during the season can build to unacceptable levels up in a well-sealed modern store, so it is always wise to ventilate periodically in stores with few natural leaks .In a storage room equipment with a $CO_2$-control system, the desired $CO_2$ levels are maintained by controlling the airflow to the scrubber or by regulating the outflow into the storage area. There are four main reagents, which are commercially used for $CO_2$ absorption. They are: water, hydrated lime, activated charcoal, and molecular sieve. In these systems, the $O_2$ levels are usually maintained by introducing outside air into the storage room(H.Kibar, 2012).

## 3. FUTURE DIRECTION FOR SEED TUBER QUALITY IMPROVEMENT

There are various ways of campaign the problem of quality of potato tuber seed loss in Developing countries like Ethiopia. The most important of which is improving the skills and knowledge of the stakeholders with respect to the postharvest handling of potato tuber seed. All stakeholders should be made aware of the best practices relevant to this produce and be able to implement it. However, the most important, is that appropriate government policies and regulations be established and implemented to stimulate national and regional development. training of all potato producers, laborers, and merchants with respect to the basic science and suitable handling of potato tuber seed at all postharvest stages could significantly reduce quality losses which currently experienced by our producers. This training could be delivered by government bodies, nongovernment organizations, farmer groups, and others, via mass media services (Use of different media helps to create awareness on use of improved varieties and healthy seed), community lectures, demonstration farms, and school curricula. Moreover the following points should be considered in improving the quality of potato tuber seed and solving the problem associated with the quality of potato tuber seed.

a. Proper technical advice of potato producers enabling them to produce high quality seed through their own management and use of quality seed leads to increased tuber yields at farm level.
b. Producers should have to invest in the diffused light storage (DLS) as it is important in storing potato tuber seed for months.
c. Alternative pre- and post-harvest technologies have to be embraced. Through more, pre- and post-harvest technologies may aid the preservation, enhancement, and viability of future tuber quality.
d. Top priority should be given to the improvement of seed health in all seed systems.
e. Working in partnership is important for technology dissemination;
f. Farmers should have to be keen on improved technologies (other agricultural technologies);
g. Organizing farmers into cooperatives also helps to reach more farmers in technology dissemination.

## 4. CONCLUSIONS

In Ethiopia potato seed tuber is constrained by both pre harvest and postharvest factors. Factors that are affecting the quality of potato seed tuber are; uses of traditional production technology, climatic factors, disease and insect pest, lack of improved storage and absence modern post-harvest handling technologies. In the production of potato, quality of seed potatoes is an important determinant of the yield and quality of the final. Hence, to increase potato production and productivity calls for improvement of the quality of seed potato with in the country is very important. Therefore, as the quality of the potato tuber seed and thereby the importance obtained from the seed is concerned the production system, transportation, storage, marketing and treatment methods should be improved through integrated manner.

## 5. ACKNOWLEDGEMENT

I would heartedly like to thank and praise the Lord Almighty God in giving me strength and wellbeing to successfully complete this review. I also sincerely thank my spouse Italem Zerfu Segni and my colleagues for their unreserved comments and encouragement. Finally, all the reference materials used in this review paper are dully acknowledged.

## 6. REFERENCES

Adane Hirpa, Miranda P. M., Meuwissen & Agajie Tesfaye Willemien J. M. Lommen & Alfons Oude Lansink, Admasu Tesfaye Paul C. Struik. (2010) . Analysis of Seed Potato Systems in Ethiopia. Am. J. Pot Res 87:537–552 DOI 10.1007/s12230-010-9164-1

Agajie, T., K. Wachira, M. Gebre, G. Wolde, L. Berga and N. Demeke, 2007. Adoption and impact of potato production technologies in selected districts of Oromiya and Amhara Regions of Ethiopia. Ethiopian Institute of Agricultural Research, Research Report.
Alamar, M.C., Tosetti, R., Landahl, S., Bermejo, A and Terry, L.A., 2017. Assuring Potato Tuber Quality during Storage: A Future Perspective. Front. Plant Sci. 8:2034. doi: 10.3389/fpls.2017.02034
Aliye, N., C. Fininsa and Y. Hiskias, 2008. Evaluation of rhizosphere bacterial antagonists for their potential to bio protects potato (*Solanum tuberosum* L.) against bacterial wilt (Ralstonia solanacearum). Biol. Control, 47: 282-288.
Almekinders, C.J.M., N.P. Louwaars and G.H. De Bruijn, 1994. Local seed systems and their importance for an improved seed supply in developing countries. Euphytica, 78: 207-216.
Amede, T., L. German, S. Rao, C. Opondo and A. Stroud, 2006. Integrated natural resource management in practice: Enabling communities to improve mountain livelihoods and landscapes. Proceedings of the African Highlands Initiative Conference, October 12-15, 2004, Nairobi, Kenya, pp: 12-15.
Bayeh, M., A. Refera, B. Wubshet, and B. Asayehegn. 2008. Potato pest management. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 97–112. Addis Abeba: Ethiopian Institute of Agricultural Research.
Bekele, K., and B. Eshetu. 2008. Potato disease management. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 79–96. Addis Abeba: Ethiopian Institute of Agricultural Research.
De Meulenaer, B., De Wilde, T., Mestdagh, F., Govaert, Y., Ooghe, W., Fraselle, S.,et al. (2008). Comparison of potato varieties between seasons and their potential for acrylamide formation. J. Sci. Food Agric. 88, 313–318. doi: 10.1002/jsfa.3091
Driskill, E. P., Knowles, L. O., and Knowles, N. R., 2007. Temperature-inducedchanges in potato processing quality during storage are modulated by tuber maturity. Am. J. Potato Res. 84, 367–383. doi: 10.1007/BF02987183
Elmore, J. E., Briddon, A., Dodson, A. T., Muttucumaru, N., Halford, N. G., and Mottram, D. S., 2016. Acrylamide in potato crisps prepared from 20 UK grown varieties: effects of variety and tuber storage time. Food Chem. 182, 1–8.doi: 10.1016/j.foodchem.2015.02
Endale, G., W. Gebremedhin, and B. Lemaga, 2008a. Potato seed management. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 53–78. Addis Abeba: Ethiopian Institute of Agricultural Research.
Endale, G., W. Gebremedhin, K. Bekele, and B. Lemaga, 2008b. Postharvest management. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 113–130. Addis Abeba: Ethiopian Institute of Agricultural Research.
FAO, 2008. Potato world Africa: International year of the potato 2008. Food and Agriculture Organization (FAO), Rome, Italy. http://www.fao.org/potato-2008/en/world/africa.html.
Foukaraki, S. G., Cools, K., Chope, G. A., and Terry, L. A. 2016a. Impact of ethylene and 1-MCP on sprouting and sugar accumulation in stored potatoes. Postharvest Biol. Tec. 114, 95–103. doi: 10.1016/j.postharvbio.2015.11.013
Fuglie, K.O., 2007. Priorities for potato research in developing countries: Results of a survey. Am. J. Potato Res., 84: 353-365.
Gebre, E. and G.W. Giorgis, 2001. Effects of spatial arrangement on tuber yields of some potato cultivars. Afr. Crop Sci. J., 9: 67-76.
Gebremedhin woldegeorgis, E. Gebre and B. Lemaga, 2008. Potato variety development. pp. 15-32. In Root and tuber crops. Ethiopian Institute of Agricultural Research.
Getachew, T. and A. Mela, 2000. The role of SHDI in potato seed production in Ethiopia: Experience from Alemaya integrated rural development project. Proceedings of the 5th African Potato Association Conference, Volume 5, May 29-June 2, 2000, Kampala, Uganda, pp: 109-112.
Gildemacher, P., P. Demo, I. Barker, W. Kaguongo, W. Gebremedhin,W.W. Wagoire, M. Wakahiu, C. Leeuwis, and P.C. Struik. 2009b.A description of seed potato systems in Kenya, Uganda and Ethiopia. American Journal of Potato Research86: 373–382.

Gildemacher, P., P. Demo, P. Kinyae, M. Nyongesa, and P. Mundia, 2007. Selecting the best plants to improve seed potato.LEISA Magazine 23(2): 10–11

Gildemacher, P., W. Kaguongo, O. Ortiz, A. Tesfaye, W. Gebremedhin,W.W. Wagoire, R. Kakuhenzire, P. Kinyae, M. Nyongesa, P.C.Struik, and C. Leewis. 2009 a. Improving potato production in Kenya, Uganda and Ethiopia. Potato Research52: 173–205

Guenthner, J.F. 2006. Development of on-farm potato seed tuber production and marketing scheme. Agricultural economics extension series no. 06-01, July 2006. University of Idaho, Moscow.

Hakan KIBAR, 2012.Design and management of postharvest Potato (*Solanum tuberosum* l.) storage structures. Ordu Univ. J. Sci. Tech., Vol:2, No:1, 23-48

Hardy, B., P. Malagamba and C. Martin, 1995. True Potato Seed in the Middle East and Africa: Proceedings of an International Workshop Held in Cairo, Egypt, April 9-15, 1994. International Potato Center, Egypt, ISBN-13: 9789290601753, Pages: 97.

Haverkort, A.J., P.C. Struik, R.G.F. Visser and E. Jacobsen, 2009. Applied biotechnology to combat late blight in potato caused by Phytophthora infestans. Potato Res., 52: 249-264.

Haverkort, A.J., 1990. Ecology of potato cropping systems in relation to latitude and altitude. Agric. Syst. 32:251-272.

Hewett, E.W. (2006). 'An overview of preharvest factors influencing postharvest quality of Horticultural products', Int. J. Postharvest Technology and Innovation, Vol. 1, No. 1, pp.4–15.

Kooman, P.L., M. Fahem, P. Tegera, and A.J. Haverkort. 1996. Effects of climate on different potato genotypes 2. Dry matter allocation and duration of the growth cycle. European Journal of Agronomy 5:207-217.

Lemaga, B., G. Haile Mariam, and W. Gebremedhin. 1994. Prospects of seed potato production in Ethiopia. In Proceedings of the second national horticultural workshop of Ethiopia, ed. E. Hareth and D. Lemma, 254–275. Addis Abera: Institute of Agricultural Research and FAO.

LeMonte, J.L., T.W. Taysom, B.G. Hopkins, V.D. Jolley and B.L. Webb, 2009. Residual soil nitrate and potato yield with polymer coated urea. Western Nutr. Manage. Conf., 8: 77-81.

Lommen, W.J.M. 1994. Effect of weight of potato minitubers on sprout growth, emergence and plant characteristics at emergence. Potato Research27: 315–322.

Lommen, W.J.M., and P.C. Struik. 1994. Field performance of potato minitubers with different fresh weights and conventional tubers: Crop establishment and yield formation. Potato Research37:301–313.

Medhin,G., A. Solomon, E. Gebre and B. Kassa, 2000. Multi location testing of clones in Ethiopia. Progress Report, Ethiopian Agricultural Research Organization (EARO), Ethiopia.

Mulatu, E., E.I. Osman, and B. Etenesh. 2005a. Improving potato seed tuber quality and producers' livelihoods in Hararghe, Eastern Ethiopia. Journal of New Seeds 7(3): 31–56.

Muttucumaru, N., Powers, S. J., Elmore, J. S., Dodson, A., Briddon, A.,Mottram, D. S., et al. (2017). Acrylamide-forming potential of potatoes grown at different locations, and the ratio of free asparagine to reducing sugars at which free asparagine becomes a limiting factor for acrylamide formation. Food Chem. 220, 76–86. doi: 10.1016/j.foodchem.2016.09.199

Nesbitt, J. E., and Adl, S. M. 2014. Differences in soil quality indicators between organic and sustainably managed potato fields in Eastern Canada. Ecol. Indic. 37, 119–130. doi: 10.1016/j.ecolind.2013.10.002

Pavek, M.J. and R.E. Thornton, 2009. Planting depth influences potato plant morphology and economic value. Am. J. Potato Res., 86: 56-67.

Pehrson, L., R.L. Mahler, E.J. Bechinski and C. Williams, 2010. Water management practices used in potato production in Idaho. Am. J. Potato Res., 87: 253-260.

Sileshi, G. and J. Teriessa, 2001. Tuber damage by potato tuber moth, Phthorimae operculella Zeller (Lepidoptera: Gelechiidae), in the field in Eastern Ethiopia. Int. J. Pest Manage. 47: 109-113.

Sthapit, B., R. Ram, C. Pashupati, B. Bimal, and S. Pratap, 2008. Informal seed systems and on-farm conservation of local varieties. In: Farmers, seeds and varieties: supporting informal seed supply in Ethiopia.

Struik, P.C. and S.G. Wiersema, 1999. Seed Potato Technology. Wageningen University Press, Wageningen, Netherlands, and ISBN-13: 9789074134651, Pages: 383.

Suttle, J.C., 2004. Physiological regulation of potato tuber dormancy. Am. J. Potato Res., 81: 253-262.

Tan, B., Huang, Z., Yin, Z., Min, X., Liu, Y. G., Wu, X., et al., 2016. Preparation and thermal properties of shape-stabilized composite phase change materials based on polyethylene glycol and porous carbon prepared from potato. RSC Adv. 6,15821–15830. doi: 10.1039/C5RA25685B

Tesfaye, A.B., K. Bedane, C. Yirga, and Gebremedhin, 2008. Socioeconomics and technology transfer. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 131–152. Addis Abeba: Ethiopian Institute of Agricultural Research.

Westermann, D.T. and G.E. Kleinkopf, 1985. Nitrogen requirements of potatoes. Agron. J., 77: 616-621

Yilma, S., 1989. The potential of true potato seeds in potato production in Ethiopia. Acta Hort., 270: 389-394.

Gawronska, H., and R.B. Dwelle, 1989. Partitioning of photoassimilates by potato plants (Solanum tuberosum L.) as influenced by irradiance I. Partitioning patterns in cultivar Russet Burbank grown under high and low irradiance.Am. Potato J. 66:201-213.

Gawronska, H., R.B. Dwelle, and J.J. Pavek, 1990. Partitioning of photoassimilates by potato plants (Solanum tuberosum L.) as influenced by irradiance II. Partitioning patterns by four clones grown under high and low irradiance.Am. Potato J. 67:163-176.

Ingram, K.T., and D.E. McCloud, 1984. Simulation of potato crop growth and development. Crop Sci. 24:21-27.

Kincaid, D.C., D.T. Westermann, and T.J. Trout, 1993. Irrigation and soil temperature effects on Russet Burbank quality. Am. Potato J. 70:711-723.

Ku, S.B., G.E. Edwards and C.B. Tanner, 1977. Effects of light, carbon dioxide, and temperature on photosynthesis, oxygen inhibition of photosynthesis, and transpiration in Solanum tuberosum. Plant Physiol. 59:868-872.

Manrique, L.A., and R.E. Meyer,1984. Effect of soil mulches on soil temperature, plant growth and potato yields in an aridic isothermic environment in Peru. Turrialba 34:413-420.

Marshall, J.K,1967. The effect of shelter on the productivity of grasslands and field crops. Field Crop Abstract 20:1-14.

Midmore, D.J., D. Berrios, and J. Roca, 1986a. Potato (Solanum spp.) in the hot tropics. II. Soil temperature and moisture modification by mulch in contrasting environments. Field Crops Res. 15:97-108.

Midmore, D.J., J. Roca, and D. Berrios, 1986 b. Potato (Solanum spp) in the hot tropics. III. Influence of mulch on weed growth, crop development, and yield in contrasting environments. Fields Crops Res. 15:109-124.

Midmore, D.J., 1988. Potato (Solanumspp.) in the hot tropics. VI. Plant population effects on soil temperature, plant development and tuber yield. Field Crops Res. 19:183-200.

Midmore, D.J. 1990. Influence of temperature and radiation on photosynthesis, respiration and growth parameters of the potato. Potato Res. 33:293-294.

Midmore, D.J., and R.K. Prange, 1992. Growth responses of two Solanum species to contrasting temperatures and irradiance levels: relations to photosynthesis, dark respiration and chlorophyll fluorescence. Annuals of Botany 69:13-20.

Moreno, U., 1985. Environmental effects on growth and development of potato plants. p 481-501. InP.H. Li (ed.) Potato Physiology. Academic Press, Inc. Orlando, FL.

Pavlista, A.D., 2002. Environmental effects. Nebraska Potato Eyes 14:1-4. Available at http://www.panhandle.unl.edu/peyes.htmAccessed on 20 April 2005.

Sale, P.J.M. 1979. Growth of potatoes (Solanum tuberosum L.) to the small tuber stage as related to soil temperature. Aust. J. Agric. Res. 30:667-675.

Sarquis, J.I., H. Gonzalez, and I. Bernal-Lugo, 1996. Response of two potato clones (S. tuberosum L.) to contrasting temperature regimes in the field. Am. Potato Res. 73:285-300.

Sturrock, J.W., 1981. Shelter boosts crop yield by 35 percent: also prevents lodging. New Zealand J. Agric. 143:18-19.

Sun, D., and G.R. Dickinson, 1997. Early growth of six native Australian tree species in windbreaks and their effect on potato growth in tropical northern Australia. For. Ecol. Manage. 95:21-34.

Tai, G.C.C., D. Levy, and W.K. Coleman, 1994. Path analysis of genotype-environment interactions of potatoes exposed to increasing warm-climate constraints. Euphytica 75:49-61.

Tibbitts, T.W., W. Cao, and S.M. Bennett, 1992. Utilization of potatoes for life support in space. V. Evaluation of cultivars in response to continuous light and high temperature. Am. Potato J. 69:229-237.

Van Heemst, H.D.J., 1986. The distribution of dry matter during growth of a potato crop. Potato Res. 29:55-66

Wheeler, R.M., T.W. Tibbitts, and A.H.Fitzpatrick, 1989. Potato growth in response to relative humidity. HortScience 24:482-484.