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Assessment of plant growth regulators and chemicals for potato (*Solanum tuberosum* L.) dormancy breaking and subsequent yield in central highlands of Ethiopia

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Abstract
The production of potato in two or more cycles within a year is increasing in the country and it is a common practice in most potato producing regions of Ethiopia. However, the characteristic long tuber dormancy of improved potato varieties in Ethiopia constrains double or triple cropping using irrigation during the long dry season of the year. Thus, it is important to break the long dormancy of tubers for early sprouting and timely planting. Therefore, several types of researches were conducted so far to assess the effect of plant growth regulators and other chemicals to assess its effect on tubers dormancy break, sprouting, sprouts growth, and subsequent effect on tuber yield, yield related and tuber quality of potato varieties. For dormancy break, sprouting and subsequent yield various methods of applications (haulm & dipping) and concentration rates were applied. Moreover, the effect of dormancy-breaking treatment and storage methods were conducted. Results of the studies indicated that, tuber dormancy period and sprout vigour were significantly influenced by the interaction of GA_3 and variety, while other sprouting as well as sprout growth traits were significantly influenced by the main effects of GA_3 and varieties. The interaction effect of varieties and GA_3 significantly influenced days to maturity. Planting of tubers treated with the highest concentration of GA_3 produced a significantly highest marketable tuber yield. The optimum tuber size (medium size) for planting purpose was attained from planting of tubers treated with 40 ppm GA_3. Significant increase in tuber number and weight due to GA_3 application contributed to the increase of total tuber yield. Application of GA_3 and storage methods as well as the interaction among the varieties and treatments significantly affected tuber dormancy period, sprouting characteristics and subsequent tuber yield. The mean values for tuber quality (DM & SG) related traits increased in response to treating the tubers with higher concentrations rate of GA_3 for both methods of application. Potato varieties treated with GA_3 showed significantly higher tuber dry matter yields, specific gravity and total starch content than the other variety. The highest net benefit with an acceptable marginal rate of return was attained in response to treating tubers with higher rates of GA_3. Therefore, it could be concluded that haulm application and dipping tuber in GA_3 at higher concentration increased tuber yield with a possibility of cultivating potato for two to three production cycles in a year that enhance productivity per unit area, food and nutrition security as well as farmers' income.

Keywords: Gibberellic acid, chemicals, dormancy, sprouting, tuber yield, dry matter content

1. Introduction
Potato (*Solanum tuberosum* L.) is one of the staple food crops in most parts of the world. It is the most consumed food crop world-wide next to wheat and rice (Birch *et al*., 2012; Hancock *et al*., 2014) [9,37]. The high yield potential of potato and its plasticity to environmental regimes makes it as one of the best crops for food and nutrition security in Eastern Africa (Kyamanywa *et al.*, 2011) [50]. It contributes to world food security and has a critical role to play in developing nations facing hunger. According to FAO, potato production in Africa tripled from 1994 through 2011, from 8 to 24 million metric tons, largely due to the increase of cropping area. Same FAO data shows that the total production in Africa which was only 4% of global supply increased to 9% ten years later. However, food demand is increasing along with global population and average income (Lobell *et al*., 2009; Monfreda *et al*., 2008) [53, 63]. Ethiopia has possibly the greatest potential for potato production; 70% of its arable land mainly in highland areas, above 1500 m.a.s.l, are believed to be suitable for potato production (Harnet *et al*., 2014) [38]. Despite high potential

production environments and marked growth, the national average potato yield in Ethiopia is 14.18 t ha^{-1} (CSA, 2019) [19], which is lower than the experimental yields of over 35 t ha^{-1} (Gebremedhin *et al*., 2013) [32] and world average yield of 20 t ha^{-1} (FAOSTAT, 2019) [31] as well as other top potato producing countries in Africa. The low yields are the result of a number of production constraints mainly involving abiotic and biotic stress factors (Hirut *et al*., 2016)[43]. Among the biotic constraints late blight, bacterial wilt, virus diseases and potato tuber moth constitute the major threats to potato production, while the abiotic stresses include soil nutrient deficiency, frost, drought, erratic rainfall, and air and high soil temperature especially in marginal areas (Gildemacher *et al*., 2009; Baye and Gebremedhin, 2013; Semegn *et al*., 2015) [34, 6, 79]. Moreover, lack of good tuber quality among growers is a major problem that adversely affects the expansion of potato production in many developing countries (Crissman *et al*., 1993) [18]. One major problem facing production of quality potato tuber is poor sprouting, due to dormancy which leads to delayed planting and poor crop emergence and vigor (Wiersema, 1985) [109]. After harvest, normal tubers show dormancy for about 1−15 weeks, depending on cultivar, tuber size, conditions before harvest and storage conditions. Farmers mostly prefer various traditional storage methods to enhance sprouting. Potato tubers sprouted in traditional ways are however, of poor quality due to apical dominance, rotting and sprout etiolating caused by the dark conditions.

The use of low quantities of different dormancy breaking treatments, such as gibberellic acid (GA_3) (Carrera *et al*., 2000; Demo *et al*., 2004) [15, 25], thiourea, rindite, carbon disulphide and bromo-ethane (Bryan, 1989) [11] has been suggested to promote potato tuber sprouting for immediate planting after harvest. However, under laboratory conditions gibberellins have been shown to be more stimulatory to potato tuber sprouting (Carrera *et al*., 2000) [15] and maintenance of tuber quality in terms of tuber health and vigor (Demo, 2002) [23] than any other growth promoting substances. Endogenous hormones have been proposed to play a significant role in tuber dormancy regulation (Suttle, 2004b) [89]. The level of endogenous GAs remains low during the middle period of storage (deep dormancy) and increase near the onset of dormancy (Bruinsma *et al*., 1967) [10]. Thus, exogenous application of GA_3 is used to break potato tuber dormancy (Hemberg, 1958) [41]. Dipping or soaking of tuber in to GA_3 solution on wounded tuber break the dormancy of tuber (Rappaport *et al*., 1958) [69]. By treating the tubers using gibberellic acid, the tubers will sprouts faster and the tubers treated with GA_3 produce more number of tuber tubers (Rehman *et al*., 2001) [71]. To date, there is scarce information on the use of GA_3 for potato sprouting under diffused light storage (DLS) conditions in eastern Ethiopia. Gemeda *et al*. (2017) [33] reported that for tubers treated with 20 ppm GA_3 and stored under farm yard manure (FYM), the tuber dormancy period was reduced from 102.5 to 52 and 36.5 to 31 days, respectively.

Timely availability of well-sprouted tubers at the on-set of rain as well as for irrigation is a pre-requisite for attaining proper planting materials which leads to high yields. Due to unavailability of sprouted tubers for planting at desired time, small scale farmers often promote potato sprouting by placing them in pits, sacks, teff straw and trenches and use genotypes with short dormancy. Medium to long dormancy genotypes are thus not easy to incorporate in the predominant cropping system in which farmers retain tuber from the previous harvest for replanting the next season. Potato producers' farmers mostly prefer various traditional storage methods to enhance sprouting. Potato tubers sprouted in traditional ways are, however, of poor quality due to apical dominance, rotting and sprout etiolation caused by the dark conditions. Under Ethiopian condition, the utilization of chemicals and plant growth regulators to regulate potato dormancy is not common. This is attributed to the lack of information regarding suitable chemicals and plant growth regulators, and their methods, rates, and time of application for efficient use. Moreover, potato producer farmers demand potato varieties having short dormancy period with desirable tuber qualities to use the varieties for multiple production cycles in a year. However, such varieties are not recommended for production by research because short tuber dormancy is considered a disadvantage for tuber storability or shelf life of table potato. Therefore, it is necessary to study dormancy breaking methods that will enhance sprouting of tubers of improved potato varieties until the breeding program develops varieties with short tuber dormancy period combined with high tuber yield, disease resistance, and quality in long run. Hence, introduction of chemicals and plant growth regulators that induces dormancy breaking is vital to have early tuber planting materials. Among the commercially available plant growth regulators, gibberellins (GA_3) are widely used to break potato tuber dormancy and it can be employed under Ethiopian condition. Conversely, the efficient method of application and optimum rates of GA_3 must be identified, and its influence on the subsequent performance of the crop was studied. In general, several plant growth regulators (PGRs) were tested to determine their role in potato tuber dormancy break, tuber yield and quality in other parts of the world and promising results were reported particularly where GA_3 used under field and greenhouse conditions. Still, these PGRs have not been exploited for agricultural production in general and potato in particular. Thus, the objective of this paper is to review the different use of gibberellic acid (GA_3) application methods and concentration rates and other chemicals to break potato tuber dormancy and subsequent effect on tuber yield and qualities.

2. Production of Potato in the Ethiopia

Potato is a crop that can be used to improve food security and cash income in Ethiopia. It is one of the root crops widely grown in the country with the highest rate of growth because increasing demand and emerging markets are providing great opportunity for resource-poor farmers to generate additional income (Gebremedhin *et al*., 2013) [32]. 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*., 1992) [8]. Currently, the national average potato production in Ethiopia reached 14.18 ton ha^{-1} (CSA, 2019) [19]. The national average potato yield is very low as compared to the attainable potential yield of (40 t ha^{-1}) obtained under research conditions. This is due to narrow genetic basis of potato varieties, poor tuber quality, susceptibility to diseases and poor farmers' management (Haverkort *et al*., 2012; Tewodros, 2014) [40, 95]. Potato production is influenced by environmental factors

this process at a given site are basically air and soil temperatures, solar radiation, photoperiod, soil moisture and crop water use.

2.1 Potato Tuberization

Tuberization refers to the whole sequence of events from stolon formation to tuber induction (Vreugdenhil and Struik, 1989) [104]. Potato tuberization is a complex developmental process requiring interactions of environmental, biochemical and genetic factors (Kolomiets *et al*., 2001) [48]. It comprises the induction, initiation and growth of stolons, then cessation of stolon longitudinal growth followed by induction, initiation and growth of tubers (Sarkar, 2008) [76]. 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. Well before plant emergence the developing sprout grows adventitious roots, which constitute the root system. The underground portion also grows in to stem called stolons, which may bear new tubers at their tips (Ewing, 1997) [28].

Several plant hormones have been suggested to play a prominent role in the control of tuberization in potato. Available evidence indicates that photoperiod, temperature, irradiance, nitrogen and physiological age of the mother tuber affect tuberization either directly or indirectly by mediating changes in hormone concentrations (Ewing, 1990)[29]. Variation in soil texture moisture tent influences tuber size and extremely high temperatures can lead to drying out of the tubers and consequently a lower yield (Ewing, 1995) [30].

2.2 Potato Tuber Dormancy

Dormancy of a potato tuber is defined as the physiological state in which autonomous sprout growth will not occur, even when the tuber is placed under conditions for sprout growth (Suttle, 2009; Reust, 1986) [91, 72]. At harvest, potato tubers are dormant and will not sprout. After harvest, normal seed tubers show dormancy for about 1−15 weeks, depending on cultivar, tuber size, conditions before harvest and storage conditions. It can also be defined as a lack of growth due to the physicochemical condition of the tuber, which is influenced by a number of factors including plant hormones and storage temperature. It begins during tuber formation when the apical meristem of the stolon no longer gives rise to longitudinal growth, whereas the sub-apical parts take over, resulting in radial growth and producing the final tuber (Vreugdenhil, 2007) [105]. The authors mentioned that dormancy gradually develops in the tuber from the moment cell division in the stolon tip has stopped and the tuber starts to develop. Dormancy is a complex process that depends on genetic background, stage of tuber development, environmental and management conditions during tuber growth and storage (Aksenova *et al*., 2013) [3]. In potatoes, dormancy is the physiological state of the tuber in which autonomous (independent) sprout growth will not occur within two weeks, even when the tuber is kept in conditions ideal for sprout growth (Van Ittersum, 1992; Struik and Wiersema, 1999) [99, 85]. During this period, postharvest environmental conditions have only limited impact on the sprouting behavior. Therefore, the period is classified as endo-dormancy. Temperature, water supply and the photoperiod during growth and storage are important environmental factors that regulate the sprouting behavior (Sonnewald, 2001) [80].

Small tubers, such as mini-tubers, even have longer periods of dormancy (Lommen, 1993)[54] and are more sensitive to adverse conditions during storage (Struik and Lommen, 1999)[83]. Smaller micro-tubers (≤250 mg) had longer dormancy periods than did those greater than 250 mg with significant difference in sprouting speed (Leclerc, 1995; Struik and Lommen, 1999) [51, 84]. Pruski *et al.* (2003) [68] reported that when dormancy of micro-tubers is not completed, less number of plants is produced. Micro-tuber dormancy appears to be correlated with field dormancy duration in cultivar specific manner (Leclerc *et al*., 1995)[51]. Endogenous hormones have been posited to plays key role in tuber dormancy regulation. Dormancy of mini-tubers is usually longer than the dormancy of normal seed tubers due to small size (Lommen, 1994) [55]. Sprouting and growth vigour of normal seed tubers also depend on seed tuber size and storage conditions (Struik and Wiersema, 1999) [85]. Larger sizes gave more vigorous sprouting and higher growth vigour of these sprouts and more weight (Van Ittersum, 1992)[99]. Small micro-tubers are more vulnerable to storage damage (Naik and Sarker, 1997) [65].

2.3 Factors Affecting Tuber Dormancy

Seed potato quality can be measured by the ability to produce sprouts and daughter tubers. In addition to cultivar characteristics, seed quality is affected by production and storage conditions (Daniels-Lake and Prange, 2007) [22]. All these factors affect the physiological characteristics of seed potatoes. The physiological state of tubers can be assessed by accumulated temperature sum, incubation period or by combining chronological age and the incubation period (Caldiz *et al*., 2001) [14]. The duration of tuber dormancy is affected by the environmental conditions that exist during tuber development on the mother plant and during storage, where temperatures lower than 10°C delay dormancy breakage and sprout development (Burton, 1989) [13]. Relevant factors include relative humidity, temperature, photoperiod and diffused light (Struik and Wiersema, 1999)[85]. Especially the temperature effect is highly complex and cultivar specific. The chemical and structural characteristics of potatoes are affected by growing conditions, variety, maturity at harvest and storage conditions (Burton, 1989) [13].

2.3.1 Genetic Variation

Dormancy of potato varies among genotypes. It may also vary within a tuber lot of one cultivar from a particular origin or year. The survival advantage, the inheritance pattern of tuber dormancy is complex and it is controlled by at least nine distinct loci (Van den Berg *et al*., 1996) [98]. In many potato cultivars, natural dormancy progression occurs over a period of many months. Usually, the dormancy period is shorter in early cultivars than in later cultivars, although this relation is not very strict. Similarly, Suttle (2007) [92] indicated that long tuber dormancy is generally found in wild potato populations whereas the reverse is often true in potato lines developed by modern breeding. The length of the dormancy period depends on the genetic background and is affected by pre-harvest and post-harvest conditions (Suttle, 2004a) [90]. With the onset of sprouting, the tuber turns into a source organ supporting growth of the developing sprout. The physiological age of the tuber has a great effect on the pattern of sprout growth, but the basis is

genetic. In turn, the physiological age of the tuber is greatly influenced by growing & storage conditions and length of storage period (Akoumianakis *et al*., 2008) [2]. The physiological status of tuber potatoes has a great impact on the emergence, number of stems per plant, number of tubers per stem, tuber-size distribution and tuber yield of the progeny crop (Struik *et al*., 2006) [84].

2.3.2 Growing Conditions

Growth conditions during tuber production (especially temperature, photoperiod, light intensity and nitrogen fertilization) can also affect the duration of dormancy (Van Ittersum, 1992) [99]. The length of dormancy period in any given variety is not constant and it varies from year to year, in addition to which the place of cultivation may influence the dormancy period (Struik and Wiersema, 1999) [85]. Potato grown in short day tends to have a shorter dormancy period. The duration of the dormancy period varies among and with condition during growth (White, 1983) [108]. The temperature at which the potato grown have a far greater influence on the length of dormancy (Scholte, 1987) [77]. According to Struik and Wiersema (1999) [84] potatoes grown at high temperature particularly at the end of growing period have shorter dormancy. The growing season or pre-harvest conditions can also affect dormancy length along with post-harvest conditions such as temperature and light (Aksenova *et al.*, 2013) [3].

2.3.3 Storage Conditions

According to, (Scholte, 1986; Struik and Wiersema, 1999; Struik *et al*., 2006) [77, 85, 84], as metabolic processes and physiological events taking place before and after dormancy differ, the sensitivity towards environmental conditions and especially towards temperature, during the different stages of physiological development of the tuber may also vary. Moreover, heat & cold shocks, and similar accumulated day-degrees built up in different ways may all have their specific effects, depending on cultivar.

Struik and Wiersema (1999) [85] described that diffused light may prevent rapid ageing of tubers. These authors stated that positive effect is realized both by effects on the development of the sprouts and on the condition of the mother tuber. The authors mentioned that the positive effect of prolonged exposure to light is cultivar specific and depends on storage temperature and photoperiod. At a temperature of 16 °C growth vigor of tubers remains highest under long days, whereas at 28 °C growth vigor decreases much faster under long days than under short days (Struik and Wiersema, 1999) [85] dormancy break and tuber initiations vary with variety and storage methods or conditions. Micro-tuber size, storage containers and conditions are significant factor for determining the viability of the micro-tuber. Therefore, gibberrlic acid, thiourea and their combinations, rindite and carbon disulfide were investigated and plays important role in dormancy breaking (Sadawarti *et al*., 2016) [74]. Thus, GA_3 application has been reported to efficiently alleviate tuber dormancy (Mosley *et al*., 2007) [64].

2.4 Dormancy Breaking and Sprouting

Dormancy is regarded as a period in the tuber life cycle from initiation to the time when sprouting starts. However, since this period is difficult to determine post-harvest dormancy is used for practical purposes and is defined as the period from dehaulming to the time when 80% of tubers show sprouts at least 2 mm long (Pande *et al*., 2007) [67]. The dormancy period varies from 2 to 3 months, depending on genotype and conditions of pre-and postharvest. Therefore, it should be evaluated before releasing any variety so that farmers are able to store their produce for a desired period of time under traditional storing conditions or in refrigerated infrastructure (Mani *et al*., 2014) [58]. Dormancy period is influenced by the age of tuber and environmental conditions that prevail during the tuber development on the mother plant and after harvest (Struik, 2007; Rehman *et al*., 2001) [82, 71].

In order to terminate premature dormancy and induce sprouting there are diverse range of physical, chemical and hormonal treatments (Coleman, 1987; Burton, 1989; Suttle, 2009) [17, 13, 91]. A number of exogenous chemicals can remove dormancy from field grown tubers (Coleman, 1987; Wiltshire and Cobb, 1996) [17, 110], but similar evaluation for micro-tubers have been limited. For quality of a particular potato clone, its dormancy period and sprouting behavior are major criteria that should be documented before any promising clone is released (Viratanen *et al*., 2013) [102]. The earliest observable stage of sprouting is characterized by visible small white buds, often termed as “pipping” or “peeping” (Sonnewald, 2001; Daniels-Lake and Prangel, 2007) [80, 22]. A tuber was considered sprouted if it had any sprouts ≥2 mm in length. Tubers with visible sprouts <2 mm in length were scored as peeping (Suttle *et al*., 2011) [88]. Initiation of dormancy break begins before the visible sprout development. In this context, researchers continue to examine the physiological processes associated with dormancy and subsequent sprout development. Dormancy breaking results in uniform tuber sprouting. It also decreases growing season and increases yield (Otroshy and Struik, 2006; Alexopoulos *et al.*, 2007a; Mohammadi *et al*., 2014) [66, 4, 62]. Morphologically, 2-3 mm initial growth of sprout is a reliable criterion for dormancy breaking of tuber.

2.4.1 Chemicals used to break dormancy of potato tuber

Plant growth regulators are chemicals that modify plant growth, flowering and dormancy by mimicking plant hormones (Kandil *et al*., 2012) [45]. Chemical dormancy breaking is an option to achieve rapid and uniform crop emergence as well as a high number of stems per plant. An endogenous plant hormones abscisic acid, cytokinins, gibberellic acid, and ethylene have been implicated in dormancy regulation (Wiltshire and Cobb, 1996) [110]. Dormancy is regulated by the relative concentrations of growth promoters and inhibitors. Gibberellins and cytokines are generally considered to be growth promoters, whereas abscisic acid and ethylene are believed to inhibit sprout growth (Sonnewald, 2001) [80]. Rehman *et al.* (2001) [71] investigated the effect of different pre-treatment components on potato tubers. The authors reported that dormancy duration was shortened in all varieties by applying chemical compounds. Among the chemicals applied for breaking down the potato nodes dormancy, one can refer to GA_3, thiourea, ethylene, ethyl bromide, and carbon disulphide (Otroshy, and Struik, 2006) [66]. On a commercial scale, Rindite, bromoethane, CS_2, GA_3 and thiourea have been used to break potato tuber dormancy. Exogenous application of thiourea, offers an economical and safe method to break potato mini-tuber dormancy (Hosseini *et al*., 2011) [44].

2.4.1.1 Gibberellic Acid (GA_3)

Gibberellic acid (also called Gibberellin A, GA, and GA_3) is a hormone found in plants. Its chemical formulae are $C_{19}H_{22}O_6$. Gibberellins are growth promoters and to date over hundred gibberellins have been isolated and mainly produced in the leaves but may also be synthesized in the root and fruits (Davies, 2010) [23], but not all are active in plants. Gibberellins contain over 136 compounds identified in various fungi and plants (MacMillan, 2002) [57]; with all containing the gibbane structure (Davies, 2010) [23]. Among these already identified GA compounds, gibberellic acid (GA_3), a fungal product, is the one most widely available, with GA_1being the most important GA in plants. GA_1 stimulates cell elongation and division in the stem, which together with cell turgor pressure, causes its elongation (Davies, 2010) [23]. GA_3 is a naturally occurring plant growth regulator which may cause a variety of effects including the stimulation of tuber germination by breaking tuber dormancy. It occurs naturally in the tubers and tubers of many species and is produced commercially by growing Gibberella fujikuroi fungus culture in vats, then extracting and purifying the GA_3 (Takahashi *et al*., 1991) [94]. Endogenous hormones have been proposed to play a significant role in tuber dormancy regulation (Suttle, 2004b) [89]. The level of endogenous GAs remains low during the middle period of storage (deep dormancy) and increase near the onset of dormancy (Bruinsma *et al*., 1967) [10]. Thus, exogenous application of GA_3 is used to break potato tuber dormancy (Hemberg, 1958; Rappaport *et al*., 1957) [41, 69]. Use of chemicals to regulate dormancy is a common practice in many countries. Being environmentally friendly and less toxic, GA_3 treatment is widely used in many countries for breaking tuber dormancy (Akoumianakis *et al*., 2008) [2].

Gibberellins are able to breaking dormancy in potato tubers (Herrera *et al*., 1991) [42]. Application of gibberellic acid on potato, either by dipping or by spraying the tuber cause to break dormancy and increasing and elongation sprouts in potatoes (Mohammadi *et al*., 2014; Lorreta *et al*., 1995; Marinus and Bodleander, 1987) [66, 56, 59]. By use of gibberellic acid in potato greater number of buds per unit area occurs because gibberellin with reduced apical dominance, increase number of stems or stolones and thereby creates greater number of tuber (Mikitzel, 1993; Salcow, 1991) [61, 73]. Alexopoulos *et al*. (2007b) [5] observed that an increase in glucose concentration in the tissues near the buds of GA-treated tubers prior to visible sprouting. These authors also found that sprouts that emerge from tubers subjected to GA treatment are thinner and longer than those that emerge from tubers in which dormancy has broken naturally. This difference may arise from the fact that tubers that break dormancy naturally have a greater physiological age, which affects membrane integrity (Knowles and Knowles, 1989) [47], whereas GA treatment increases cell division and elongation (Taiz and Zeiger, 2002)[93]. GA_3 has efficient penetration into the internal tissues of tuber (Otroshy and Struik, 2006) [66]. Since the tuber skin is a main hindrance for chemical permeation, it is advisable to apply these chemicals on tuber slices and/or on newly harvested tuber (Shekari *et al*., 2010) [78]. Dipping or soaking of tuber in to GA_3 solution break the dormancy of tuber (Rappaport *et al*., 1958) [69]. GA_3 is also applied on haulm to shorten the dormancy of potato and stimulate sprout initiation in a short period of time (Van Ittersum *et al*., 1993) [100]. To break the tuber bud dormancy or to shorten the resting period, GA_3 is reported as hormone and widely used to break potato dormancy as well as stimulating the sprouting of potato tuber (Rehman *et al*., 2001; Salimi, 2010) [71, 75]. Moreover, Salimi *et al*. (2010) [75] reported that dormancy period tended to decrease with an increase in the weight of mini-tubers, whereas the number of sprouts per mini-tuber, their length and fresh weight and the sprout mass per unit of sprout length of the longest sprout tended to increase with an increase in mini-tuber weight. Advancing breaking of dormancy was associated with removal of apical dominance. In addition, Dogonadze *et al*. (2000) [27] also observed that exogenous application of GA_3 promoted tuber sprouting by enhancing RNA and DNA synthesis. Similarly, by treating the tubers using gibberellic acid the motivation of tubers will be happened faster and the tubers treated with GA_3 produce more number of tubers (Burton, 1989; Rehman *et al*., 2001) [13, 71]. Besides playing a role in the photoperiodic control of tuberization, gibberellins are regulators in tuber formation (Xu *et al*., 2006) [111].

GA_3 application efficiently alleviates tubers dormancy (Mosley, 2007)[64]. GA_3 application effectively reduced dormancy period and time needed for mini-tubers sprout emergence. However, suitable GA_3 concentration for dormancy soothing of potato mini-tubers need to be standardized (Hassan-Panah *et al*., 2007) [39]. The micro-tubers treated with GA_3 produced thin and elongated sprouts (Rehman *et al*., 2003) [70]. GA_3 application as liquid solutions accelerated eyes growth via sprout emergence and produced more slim accessory shoots (Rehman *et al*., 2003)[70]. GA_3 application at 160 ppm is the most suitable concentration for dormancy alleviation, acceleration of seedling emergence (Shekari *et al*., 2010) [78]. GA_3 treatment after 2, 3 and 8 weeks of cold storage of mini-tubers was found best and most effective dose was 500 mg/1 GA_3 in breaking dormancy and inducing precocious sprouting (Habib, 1999) [36]. GA_3 1500 ppm and 5% thiourea decreases dormancy period from 63 days to 39 days (Hassan-Panah *et al*., 2007) [39]. GA_3 at 30 ppm application is best suitable for dormancy alleviation (Benedetti, 2005) [7] while, 5 ppm GA_3 is appropriate dose for dormancy relief and yield improvement of 'Agria', 'Marfona' and 'Gloria' potatoes (Rehman *et al*., 2003) [70].

2.4.1.2 Cytokinins

All the cytokinins originate from isopentlyladenosine can enhance micro tuberization (Wang, 1985) [106] as well as modify tuber dormancy duration depending on cultivar (Wattimena, 1983) [107]. The cytokinins most prevalent in plants are those with a N6-side chain such as zeatin, isopentenyl adenine and N6-benzyladenine (Vivanco and Flores, 2000) [103]. In field grown tubers, exogenous cytokinin can break dormancy with greatest efficacy when applied near the end of the dormancy period (Turnbull and Hanke, 1985)[97] as the concentration of endogenous cytokinin begins to increase. Thus, cytokinin induces cell division and cell expansion in sprout within 48 hrs of cytokinin injection (Sukhova *et al*., 1993) [87]. These authors examined Kinetin and Zeatin is known to break dormancy in potato tubers.

2.4.1.3 Rindite
Promoting early establishment in potato tubers may be achieved by chemical treatment. Rindite (7:3:1 anhydrous ethylene chlorohydrin: ethylene dichloride: carbon tetrachloride), have been used to break potato tuber dormancy and to hasten sprouting (Denny, 1984) [26]. However, chemical treatments such as Rindite pose high toxicity risks, both for the workers handling the chemicals and for the environment. It was used extensively by the formal tuber production system to break potato tuber dormancy and promote sprouting. Though very effective, Rindite is toxic thus environmentally unfriendly and damaging to human health (Rehman *et al*., 2001) [71] and hence its use is discouraged. It is the effective dormancy release for microtubers and field tubers however, as stated above their mutagenicity, carcinogenicity and toxicity make their commercial use unacceptable (Kim *et al*., 1997; Wattimena, 1983) [46, 107]. Rindite proved to be a much more effective dormancy breaking treatment than gibberellins (Pruski *et al*., 2003) [68].

2.4.1.4 Auxin
Auxins are essential cognate regulators of cell cycle progression in all plant tissues (Francis and Sorrell, 2001) [32]. The most important naturally occurring auxin is indole-3-acetic acid (IAA). The authors mentioned that, such threshold levels of auxin such as indole- 3-acetic acid (IAA) would be required for sprout growth, but would not be the initiators of dormancy. Thus auxins do not affect dormancy itself, but influence the growth of sprouts after dormancy has been broken (Alexopoulos *et al*., 2007a) [4]. The endogenous levels of auxin such as IAA are low in endo-dormant potato tubers and increase in shoot buds prior to the onset of growth (Suttle, 2004b) [89]. The author mentioned that, at relatively high doses exogenous auxins such as IAA and the more stable 1-naphthalene acetic acid were found to be potent inhibitors of sprout growth. In potatoes changes in endogenous levels of the auxins (IAA) are suggested to be more closely related to the regulation of subsequent sprout growth (Suttle, 2004a) [91]. The author showed that endogenous auxins levels were low until the end of dormancy and increased with sprout growth.

2.4.1.5 Ethylene
Ethylene is a naturally occurring gaseous plant hormone. It is believed to be involved in the modulation of a number of potato tuber biochemical pathways and processes such as sprouting and sprout elongation (Strom, 2007) [82]. The author stated that in general, ethylene or ethylene releasing compounds like ethephon enhance release from dormancy and increases sprouting of potato tubers. The author also suggested that, ethylene or ethylene releasing compounds also inhibit sprout elongation, which in turn makes ethylene treatment undesirable for rapid crop establishment. Ethylene production increases as sprouting commences and certain dormancy terminating agents stimulate ethylene production (Akoumiankis *et al.*, 2008; Suttle, 2009) [2, 92]. According to Timm *et al*. (1986) [97] the effect of ethylene on potato sprouting depends on the duration of exposure. Short or intermittent ethylene treatments stimulate sprouting (Timm *et al*., 1986) [97] whereas; prolonged continuous exposure to ethylene inhibits sprout elongation.

2.4.1.6 Other growth substances
Several researchers mentioned that rather than plant growth regulators various growth substances were also suspected to influence potato tuber dormancy. Some of these are; phenolic compounds, Jasmonic acid (Tuberonic acid), Brassinosteroids (BS) and volatile compounds. Potato periderm is a rich source of phenolics, and the original extracts assayed for inhibitory activity on dormancy control. Another study has demonstrated that the loss of tuber dormancy is accompanied by a reduction in phenolic acid content and an increase in phenolic conjugate levels (Cvikrova *et al*., 1994) [21]. According to Ewing (1995) [30], tuberization is a photo periodically sensitive developmental process that is stimulated under short days by leaf derived factors.

Current evidence suggests that one of these leaf factors is a jasmonic acid derivative given the trivial name tuberonic acid (Yoshihara *et al*., 1989) [112] and the role of jasmonates in tuber dormancy inception and control is unknown. Endogenous contents of jasmonic acid have been measured in developing tubers and elongating sprouts and the role of jasmonates in tuber dormancy has not been determined. Brassinosteroids (BS) are a class of endogenous plant growth substances and were originally isolated from rape tuber pollen as growth-promoting substances (Clouse and Sasse, 1998) [16]. The authors found that depending on the assay system, BS elicits a wide range of biological activities including both growth promotion and inhibition. Korableva *et al*. (2002) [50] reported that post-harvest application of 2, 4-epibrassinolide prolong tuber dormancy and increase abscisic acid (ABA) content and ethylene production. However, the effects BS content and activities on dormancy status have not been reported and, as such, the role of this interesting class of regulators in tuber dormancy remains speculative. According to Burton and Meigh (1971) [11], potato tubers produce a number of volatile compounds; several of these volatiles are potent growth inhibitors. Subsequent studies identified several bioactive volatiles including the 1, 4- and 1, 6- isomers of dimethyl-naphthalene (Meigh *et al*., 1973) [61]. Application of these dimethyl-naphthalene derivatives results in a transient inhibition of sprout growth, and a commercial product containing these isomers has been marketed for post-harvest sprouts control (Lewis *et al*., 1997) [52]. In addition, Thiourea 1% breaks dormancy, accelerated plants emergence, increased tuber number per plant, and leading to maximum yield in potato minitubers of Marfona cultivar (Germchi *et al*., 2011) [35].

3. Summary and Conclusion
Potato is cheap source of human diet and it has multi nutritional value. The production of potato in Ethiopia is not only as co-staple food but it is also cash crop for income generation in the highlands of the country. The production of potato in two or more cycles of production in a year is a common production practice in most potato production areas of the country which showed increasing trend due to expansion of small scale irrigation practices. In the country, potato varieties are recommended mainly depending on the performance of high yield and late blight disease resistance as well as long storage period of tubers. Because long shelf life of tubers is an advantage for potato producers and consumers for long period consumption and sale. However, the improved potato varieties are failed to fit the existing

practice of two or more cycles of production in a year. Thus, lack of medium-term to longer tuber dormancy periods of potato varieties released in Ethiopia is one of the main limiting factors for smallholder farmer's to access good quality tuber at the time of planting for irrigation practices adversely affecting the production and productivity of potato crop.

Therefore, various types of research were conducted so far using different GA_3 application methods and concentration rates to assess the effect of Gibberellic Acid (GA_3) on tuber dormancy, sprouting, sprouts growth, and subsequent effect on tuber yield, yield related and tuber quality of potato varieties (Abebe, 2010) [1]. The results of the studies indicated that both methods of application and various concentration rates had significant effect for tuber dormancy termination, sprouting, subsequent effect on tuber yield and tuber quality. Therefore, significant increase in tuber number and weight due to GA_3 application contributed to the increase of total tuber yield. In general, the study indicated that haulm application of GA_3 at 750 or 1000 ppm rates and dipping treatments of 40 or 50 ppm resulted in high total, marketable tuber yield and significant dry matter content and tuber specific gravity (Abebe, 2010)[1]. Moreover, the results of different concentration rate on three potato varieties showed that, the tuber dormancy period was significantly ($P<0.01$) influenced by treating tubers with GA_3 concentrations, variety and the interaction of the two. Sprouting of tubers and other sprout characteristics (number of sprout, sprout length, lateral axillary sprout, sprout thickness, weight loss of tubers, sprouts fresh and dry mass) were significantly affected by treating of tubers with GA_3 concentrations and variety but not the interaction of the two except sprout vigor (Gemeda *et al*.,2017) [33]. At the increased level of GA_3 the increased trend was observed with regard to all sprout characteristics. The largest number of sprout, the longest sprout length, thicker sprout, the highest fresh and dry mass of sprout was observed from the application rate of 40 ppm GA_3 concentration, while the lowest was for the control (Gemeda *et al*., 2017) [33].

According to the study on effects of different dormancy breaking and storage methods on tuber sprouting and subsequent yield of two potato varieties indicated that, exogenous application of GA_3 combined with different storage methods immediately after harvest resulted in a shortened dormancy period, increased sprout mass and improvements in both yield and quality (specific gravity, dry matter, and total starch content) of the subsequent potato generation (Gemeda *et al*., 2017) [33]. The authors described that, the response of potato varieties to combination of GA_3 and storage methods also differed due to genetic factors, GA_3 treatment, and storage methods. From the studies, Gemada *et al*. (2017) [33] reported that, treating tubers of an improved variety with GA_3 at 20 ppm before storage in diffused light store (DLS), pit storage (PS), or farm yard manure (FYM) promoted early dormancy termination and early emergence of shoots of high marketable tuber yield production. The result of the study indicated that both haulm application and dipping methods have effect on dormancy break, early emergency of shoots, increased tuber yield and quality of potato. From the study, for easy spray and to promote early dormancy termination, early emergency of shoots, high total and marketable tuber yield production and significant dry matter content and specific gravity, haulm applications of GA_3 at a rate of 750 ppm rates or dipping tubers in 40 ppm GA_3 solution were found to be optimum (Abebe, 2010) [1]. It can be concluded that foliar application and dipping potato tubers with GA_3 at various concentration could be used to shorten tuber dormancy so that farmers' will be able to cultivate the crops multiple times during the year using both rain-fed and irrigation. This will enhance productivity per unit area, food and nutrition security as well as producers' income.

4. References

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