Treatments of Gibberellic Acid for Vegetative Growth, Tuber Yield and Quality of Potato *(Solanum tuberosum* L.) in the Central Highlands of Ethiopia

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Abstract: The productivity of potato is low owing to a number of constraints including poor sprouting due to dormancy, which leads to delayed planting and poor crop emergence and vigor. The study was conducted during 2008-2009 with the objectives to determine the effects of different methods and rates of gibberellic acid (GA_3) application on dormancy attributes, tuber yield and quality of potato, and its subsequent generation of Gera cultivar. Five levels of GA_3 (0, 250,500,750 and 1000 ppm), as haulm application a week prior to haulm destruction, and five levels of GA_3 (10, 20, 30, 40 and 50 ppm), as dipping treatments immediately after harvest for 24hrs, were used as treatments. The treatments were arranged in randomized completed block design with three replications both for planting and storage. The result showed that GA_3 application affected dormancy period, tuber yield and quality. Haulm applications of GA_3 increased marketable tuber and tuber yield per hill as compared to untreated tubers. Moreover, haulm application of GA_3 increased dry matter content as compared to the control, while the increment in the dry matter content was also observed in response to dipping the seed tuber. In the same manner, dipping seed tubers in GA_3 solution increased tuber specific gravity of the next generation as compared to the control. Therefore, significant increase in tuber number and weight due to GA_3 application contributed to the increase of total tuber yield. Both haulm application and dipping treatments of GA_3 at higher rates resulted in high total, marketable tuber yield along with significant dry matter content and tuber specific gravity, which help the producers to boost their produce.

Keywords: Potato, Gibberellic acid, Haulm application, Dipping, Tuber yield, Dry matter & Specific gravity.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important food and cash crop in the Eastern and Central Africa, playing a major role in the national food security and nutrition, poverty alleviation and income generation, and its cultivation provides employment in the production, processing and marketing sub-sectors [1]. It is currently the third most important food crop after rice and wheat for human consumption, and is eaten by more than a billion people worldwide [2]. In Ethiopia, on top of being a key crop for food and nutrition security, potato is a vital source of income for many smallholder farmers in the Ethiopian highlands due to its high yield combined with its early maturity and high nutritional value [3-5]. Currently, potato is cultivated on more than 0.3 million ha of land in the country, engaging more than 5 million smallholder farmers with an annual production of about 3.6 million tons [6].

Ethiopia is endowed with suitable climatic and edaphic conditions for high quality potato production. Moreover, many improved cultivars with on-farm yield potential of 25-45 tones ha^{-1} were developed by research centers and demonstrated to farmers for production [7]. Even when there was a huge increment compared to the other crops growing in the highland areas during the same period of years, the potential attainable average yields of the potato crop on research and farmers' fields were 45 and 25 tons/ha, respectively [8]. The current national average production is limited to about 14.18 tons/ha [9]. Even though the production and productivity are increasing year after year, lack of good quality seed among growers is a major problem adversely affecting the expansion of potato production in many developing countries [10].

One major problem facing the production of quality potato seed is poor sprouting, due to dormancy, which leads to delayed planting and poor crop emergence and vigor [11]. Moreover, irrigated potato production has been increasing recently due to the climate variability but is limited to specific areas where there is adequate access to irrigation facilities. However, irrigated potato crop is planted any time from October-March depending on location and occurrence of frost. Recently, this practice is increasing in areas coverage across almost all agro-ecologies such as the central, southern, eastern and northern regions of the country following the government focus and efforts on the development of small and medium scale irrigation schemes with the main objective of curbing the effects of climate change and dependency on the unreliable

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single rain-fed based agricultural production system. Thus, high-value horticultural crops, such as potatoes, become important components of these newly developed irrigated crop production systems. As a result, expansion of irrigation agriculture has resulted in expansion of potato to the mid- and low-land alluvial plains, which were non-traditional potato growing areas in the country, but access to quality seed tuber is very crucial for the farmers to be successful.

The improvements of crop productivity in modern agricultural systems are increasingly dependent on the manipulation of the physiological activities of the crop by chemical means [12]. The management of potato tuber dormancy is of great importance for the ware, packing and processing markets and also for the seed industry. After harvesting, potato tuber is naturally dormant for 1-15 weeks depending on the cultivar and storage conditions [13]. Potato tuber buds normally remain dormant throughout the growing season until several weeks after harvest [14] and the conditions that influence tuber formation and growth in potatoes may influence the duration of dormancy [15]. Plant internal factors including plant hormones such as gibberellic acid, auxins, ethylene, cytokinins and abscisic acid have been known to affect potato sprouting [16]. Timely availability of well-sprouted seed tubers at the on-set of the rain as well as for irrigation is a prerequisite for attaining proper seed tuber, which leads to high yields. Due to unavailability of sprouted tubers for planting at desired time, smallholder farmers often promote potato sprouting by placing them into 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 seed from the previous harvest for replanting in the next season. Farmers mostly prefer various traditional storage methods to enhance sprouting. Potato seeds sprouted in traditional ways are, however, of poor quality due to apical dominance, rotting and sprout etiolation caused by the dark conditions. However, sprouting can be stimulated by applying chemicals (either before or after harvest), by damaging the tubers, and by manipulating the humidity of the air, the air temperature (warm storage, heat shocks, cold shocks) or the composition of the atmosphere of the storage environment [17]. However, at commercial scale, Rindite [18], bromoethane [19], CS_2 and GA_3 [20] have been used to break the potato tuber dormancy. The time of emergence, the number of main stems and branches, the onset of tuber initiation, the rate of tuber bulking, and the number and size distribution of the progeny tubers are all effected to some extent by the number and size of sprouts on the tubers used as seed tuber at the time of planting [21].

Haverkort *et al*. [22] reported that the tuber number was increased by increasing the sprout number; their results showed the validity of the concept of striving for more sprouts per seed tuber to obtain more progeny tubers as desired in the seed potato production. Thus, when studying the efficacy of chemicals to break dormancy, one should also investigate the possible effects on sprout growth patterns, as these will affect the progeny crop. Under Ethiopian condition, the utilization of chemicals to regulate the potato dormancy is not common. This is attributed to the lack of information regarding suitable chemicals and methods, rates, and time of application for efficient use. Therefore, this experiment was conducted to determine the effect of gibberellic acid on dormancy termination and subsequent vegetative growth, yield and quality of potato tubers.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The tuber dormancy breaking experiment was conducted at Holetta, which is located in the Oromia National Regional State and about 29 km far from Addis Ababa in west direction. The site, Holetta Agricultural Research Center, lies at 9° 00' N latitude, 38° 30' E longitude and with an elevation of 2400 (m.a.s.l) in central Ethiopia. The daily average minimum and maximum temperatures of the area were 6.42°C and 27.2°C, respectively, and the mean annual rainfall was 918.31 mm. The soil of the experimental site is predominantly Nitisols, which is characteristically reddish to brown in color. It has soil pH of 5.24 and clay in texture with contents of 62.5% clay, 30.0% silt, and 7.5% sand. The soil has organic matter content of 2.18%, and total nitrogen, available phosphorus and exchangeable potassium contents of 0.18%, 30.58 ppm and 0.14 meq 100 g^{-1} soils, respectively [23].

2.2. Field and Experimental Material Preparation

The experimental field was ploughed and disked with tractor before planting. During planting, the experimental plots with fine seedbed were prepared not to damage the sprouts of potato as the sprouted tubers are easily broken. A field layout was made accordingly and each treatment was assigned randomly to the experimental plots with replications. Potato cultivar, Gera, which is nationally released with a yielding potential of 25 tons/ha and having extended dormancy period of more than 90 days and having large, round and white tubers with deep eyes, was used for the experiment.

2.3. Treatments

The experiment was conducted at Holetta Agricultural Research Centre 2008-2009 both main cropping seasons and using irrigation also. For tuber dormancy break, a week before harvesting (98 days after planting), from each plot, ten plants from the central rows were tagged and treated with five different rates (0, 250, 500, 750 and 1000 ppm) of GA_3 as a foliar application. Similarly, at the time of harvest, forty medium sized (35-45 mm) and healthy tubers were selected and dipped in to five different concentrations (0, 10, 20, 30, 40 and 50 ppm) of GA_3 solution for 24 hrs. The stock solution of GA_3 was prepared by dissolving a total of 3g GA_3 (90% gibberellins A_3 Biochemical, BDH Limited Poole England) in 10 ml of ethanol (96%) and the final volume was made up to 1000 ml with double distilled water (DDW). For foliar application, the solution was applied as a fine spray using an atomizer early in the morning to avoid rapid drying of the spray solution due to transpiration. The control tubers were only treated with ethanol and DDW for the same duration.

2.4. Field Trial

To study the effect of GA_3 treatment on the subsequent growth, yield and quality of potato, a field trial was conducted. Medium sized (35-45 mm) tubers from the previous experiment were stored for 100 days in a naturally ventilated diffused light store and planted during the off-season in January, 2009 in the field using irrigation. The experimental plots of (3m x 3m) were arranged in a randomized complete block design with three replications. Forty medium sized tubers were selected and planted per plot at a spacing of 75cm x 30cm between rows and plants, respectively, in four rows having ten plants each. Phosphorus was applied at the rate 92 kg/ha, all at the time of planting, using P_2O_5 whereas nitrogen fertilizer was applied at the rate of 110 kg/ha in split form (half at planting and half at full emergence, i.e., 45 days after planting) as a side dress in the form of Urea and incorporated into the soil to facilitate efficient nutrient uptake by the roots. Dehaulming was done seven days before harvesting to enhance tuber maturity, facilitate harvesting and to reduce peeling of the tubers. Appropriate cultural practices were applied accordingly to the research recommendation [24].

2.5. Observations and Measurements

During this study, days to emergence were recorded when 50% of the plants in each plot emerged out. Days to 50% flowering were recorded when 50% of the plant population in each plot produced flowers. Plant height (cm) was measured from the soil level to the upper point of the main stem by a ruler for the five labeled plants. Average number of main stems produced per hill was taken from five randomly selected plants from each plot at full flowering. Days to physiological maturity was recorded as days from emergence to maturity when the haulms of 50% of the plant population per plot have turned yellowish or showed senescence. Average tuber number per plant was expressed as total number of tubers harvested from 20 hills divided by the number of plants harvested. Average tuber weight (g) was recorded as the ratio of the weight of tubers per plant/hill to the number of tubers per plant/hill expressed in grams at harvest. For the tuber yield per plant (g)**,** the average weight of total tuber of 20 hills was recorded as the weight of tubers harvested from a physiologically matured plant. Total tuber yield (tons/ha) was recorded as the sum of marketable and unmarketable tuber yield. Marketable tuber yield per plot (tons/ha) included healthy tubers having a size greater than 20 mm in diameter. For determining the percentage of dry matter content, 500g of cleaned unpeeled tubers were chopped and the samples were dried in an oven at a temperature of 70°C for about 72 hrs to get a constant weight. Moreover, for qualitative parameters, the dry matter content was computed by dividing the weight of the sample, after drying it, with the initial weight of the sample multiplied by hundred. The dry matter content was calculated using the following formula.

$$\text{Dry matter content (\%)} = (\text{Dry weight} / \text{Fresh weight}) \times 100$$

Specific gravity of tubers (gcm^{-3}) was computed from the recorded dry matter content. Consequently, the equation [25] of the dry matter (%) = -214.9206 + 218.1852 × (specific gravity) and 17.565 + 199.07 × (Specific gravity – 1.0988) were used to convert the dry matter value of varieties in this study to specific gravity [26]. Biomass yield was calculated to determine the dry mass of aboveground parts (stem, branch, and leaves) and underground parts (root, stolon, and parts of the stem remaining underground) of three randomly selected plants that were harvested from each treatment category at about six weeks after pollination [27] when the vines were still green but had practically ceased growth. Both above and underground parts were weighed after drying the samples in an oven at 72°C to a constant weight.

2.6. Statistical Analysis

The data was analyzed using analysis of variance (ANOVA) and treatment means were separated by Duncan Multiple Range Test (DMRT) at 1% and 5% probability level by using SAS statistical software packages version 9.00 [28].

3. RESULT AND DISCUSSION

3.1. Vegetative Growth, Yield and Quality Parameters

3.1.1. Days to Emergence

Highly significant ($P<0.01$) differences were found among treatments with regard to days to emergence of the shoots (Table **1**). Both haulm applications and dipping treatments of GA_3 significantly reduced days of emergence of treated tubers than untreated with maximum reduction of 11 days by haulm application of 1000 ppm GA_3 while dipping of 40 and 50 ppm reduced days to emergence by 6 and 8 days, respectively. Earlier emergence of GA_3 treated tubers could be attributed to their shorter dormancy and subsequent faster sprout growth. In agreement to the current findings, Gemeda *et al.*, [29] reported that early emergence is undoubtedly the result of the combined effect of GA_3 on the rest period and subsequent stimulation of sprout elongation. GA_3 applied as a foliar spray induced earlier sprouting of the subsequently harvested tubers [20]. Tuber treatment with GA_3 enhanced sprout growth and resulted in faster emergence of potatoes [30]. Specifically [31] reported that GA_3 at 50 and 100 ppm enhanced emergence by 5 and 10 days, respectively. Tubers treated with a higher concentration of GA_3 showed earlier emergence than the untreated ones according to the study [30,31].

3.1.2. Days to Flowering

Non-significant difference was observed due to haulm application and dipping of GA_3 on days to flowering (Table **1**). This could be attributed to exogenous application of GA_3 to the seed tubers than the growing potato plants. Various researchers reported that direct GA_3 application on the growing plants significantly influenced flowering in potato. El-Gizawy [32] reported that foliar applications of GA_3 induced early flowering by decreasing the time required to flowering, prolonging the duration of flowering period, and increasing the number of flowers per plant. Coleman [33] indicated that exogenous applications of GA_3 have long been used to break dormancy in potato seed tubers and also to enhance flowering.

Table 1: Effects of Seed Tubers Treatment with Gibberellic Acid on Days to Emergence, Days to Flowering, Stem Number Per Hill and Height of Potato Plants

Treatments	Days to Emergency	Days to Flowering	Stem Number Per Hill	Plant Height (cm)
Control (Ethanol and DDW)	34.00^{a}	87.67	2.58	82.50^{f}
Haulm application of 250 ppm GA_3	27.00^{bc}	84.67	2.67	86.25^{cd}
Haulm application of 500 ppm GA_3	24.67^{de}	86.33	2.42	87.33^{bc}
Haulm application of 750 ppm GA_3	23.33^{ef}	83.00	2.67	88.58^{ab}
Haulm application of 1000 ppm GA_3	22.67^{f}	88.00	2.67	89.83^{a}
Dipping tubers in 10 ppm of GA_3	28.67^{b}	86.33	2.50	83.52^{ef}
Dipping tubers in 20 ppm of GA_3	27.33^{bc}	85.33	2.33	83.75^{ef}
Dipping tubers in 30 ppm of GA_3	27.67^{bc}	83.67	2.67	83.92^{ef}
Dipping tubers in 40 ppm of GA_3	28.33^{b}	83.33	2.92	84.75^{de}
Dipping tubers in 50 ppm of GA_3	26.33^{cd}	84.67	2.58	85.70^{cd}
Mean	27.00	85.3	2.57	85.61
CV (%)	3.89	3.36	15.56	1.13
Level of Significance	**	ns	ns	**

Means within a column followed by the same letters are not significantly different at the prescribed level of significance. **, ns = significant at 1% and non- significant at 5% probability level, respectively.

3.2. Stem Number Per Hill

Non-significant difference was observed with regard to stem number per hill among the treatments (Table **1**). In line with the present study, Gemeda *et al*. [29] reported that no difference in number of stems per hill was found in their experiment conducted on four potato varieties treated with various rates of GA_3. Similarly, Abebe, [20] reported that dipping potato tubers having a larger size, i.e., between 35 - 45 mm, in 25 ppm GA_3 solutions had no effect on the number of stems, but affected the number of sprouts. Moreover, Bryan, [34] stated that tubers, whose dormancy is broken by chemical treatment often show apical dominance, which resulted in reduction of stem number per hill. Moreover, Morena *et al*. [35] indicated that the number of stems per plant (hill) is influenced by variety. Therefore, the lack of significant differences among the treatments in the current investigation with regard to stem number per hill could be due to the inherent genetic character of the variety in the number of buds produced per tubers. According to Beukema and van der Zaag, [36], the number of main stems per plant is one of the elements determining stem density, which subsequently affects the tuber yield. It also affects the tuber size and the tuber number distribution [37].

3.2.1. Plant Height

Seed tuber treatment with GA_3 significantly influenced plant height of the immediate generation of potato as presented in (Table **1**). Haulm application of 750 or 1000 ppm increased plant height by about 8% as compared to the control (82.5 cm). In the same manner, approximately 4% plant height increment was observed in response to dipping tubers in 50 ppm GA_3 solution as compared to the untreated tubers. The observed plant height increment in response to GA_3 treatment could be related to its effect on internodes elongation and shoot growth. In favor of the current finding, Alexopoulos *et al*., and Sharma and Gupta, [38,39] observed an increase in plant height, number of nodes and internodes length when GA_3 was applied for 60 days after planting. According to Alexopoulos *et al*. [38], GA_3 treatment increased plant height by increasing both internodes length and number of nodes per plant.

Alexopoulos *et al*. [38] observed that foliar application of GA_3 to potato plants derived from true potato seeds caused an increase in plant height similar to that reported for the potato plants from seed tubers. In the same manner, Sharma and Gupta, [39] found that single application of GA_3 to potato plants derived from the true potato seeds caused an increase in plant height similar to that reported for potato plants derived from seed tubers. Moreover, Struik *et al*., [40] reported that soil application of various concentrations of GA_3 at different days after planting concluded that the application of GA_3 at 20 days after planting resulted in the highest plant height.

3.2.2. Days to Physiological Maturity

Highly significant (P<0.01) difference was found among treatments with regard to days to physiological maturity and haulm applications of 1000 ppm and 750 ppm resulted in earlier physiological maturity of 108 and 110 days, respectively, as compared to the control, which takes 120 days to mature (Table **2**). Regardless of the concentration, all dipping treatments did not significantly affect days to physiological maturity of the potato plants that may be due to the lower concentration to penetrate the intact tuber tissue and also late emergence of shoots. In supporting this view, Caldiz *et al*., [41] reported that the tubers having shorter dormancy period senesce earlier, and produce more tubers but of smaller size. In addition, Lim *et al*., [31] examined that leaves from GA_3 sprayed potato plants turned pale-green and showed early senescence than the untreated control plants.

3.2.3. Average Tuber Number

Highly significant (P<0.01) difference was found among treatments with regard to average tuber number per hill (Table **2**). The highest tuber number per plant (10.12) was recorded from haulm application of 1000 ppm GA_3 followed by haulm application of 750 ppm GA_3, which are statistically equal values. This indicates that number of tubers initiated by individual plant could be influenced by the GA_3 treatments, which could be affecting stolon initiation and branching. In favor of this view, Caldiz [42] found that the effect of GA_3 on tuber number was mainly due to an increase in the length and branching of the main stolons, which increased the number of tuber sites. The author also showed that foliar applied with GA_3 significantly increased tuber number either if applied alone or in combination with cytokinins, while no effects of cytokinins alone were found. Similarly, Abebe, [20] found that GA_3 stimulates stolon production as well as sprout growth, and the increased tuber number may be due partly to the greater number of stems and partly to a stimulation of stolon production, as also found by Gemeda *et al*., [29]. The increase in average tuber number might be due to the increased photosynthetic activity and translocation of photosynthate to the root, which might have helped in the initiation of more stolon in potato according to Annad and Krishnappa, [43]. Bandara *et al*., [44] reported that when plants were treated once with GA early in their growth cycle, the number of tubers per plant increased, but this effect is critically dependent on the time of application [45]. Tuber number is also determined by the number of stems produced, which in turn depends up on the tuber size and variety as reported by Ebwongu *et al*., [46].

In agreement with this study, Kustiati *et al*. [47] reported that application of GA_3 to physiologically young seeds increased tuber number per plant although there was differential response of cultivars to the treatment. Alexopoulos *et al*. [38] found that haulm application of GA_3 30 days after planting caused a significant increase in the number of tubers per plant and the effect of GA_3 on tuberization is generally higher when the application is repeated. Alexopoulos *et al*. [48] also reported that foliar application of GA_3 increased the number of tubers formed per plant, but reduced mean tuber size. Number of tubers produced can be strongly increased by foliar application of GA_3 according to Struik *et al*., [40].

3.2.4. Average Tuber Weight

Highly significant difference was observed among treatments with regard to average tuber weight (Table **2**). Haulm applications of 750 or 1000 ppm GA_3 improved average tuber weight by almost 10% in reference to the control (82.20g). Dipping tubers in 50 ppm of GA_3 solution increased the average tuber weight from 82.20g to 86.00g, bringing almost 5% increments. An increase in the average tuber weight may be attributed to early crop emergence and an increase in photosynthetic area in response to GA_3 treatment that maximized the rate of assimilates production.

In favor of the current findings, Struik *et al*. [40] found that GA_3 applied at a higher dose to the soil, during the time of tuber initiation, increased the yields in the smaller classes (0-40 g) while late application, 80 days after planting, stimulated the production of very large tubers, which is in line with the current result. Average tuber weights in potato has been reported to be the most important yield component known to significantly influence total tuber yield [35].

In contrary to the current finding, exogenous GA_3 treatment early in the growth cycle proved to decrease average tuber weight thereby final tuber yield. According to Sharma *et al*. [39] exogenous GA_3 is known to decrease tuber weight and tuber to shoot ratio. The authors described that at early stages of development, there is rapid haulm growth of GA_3 treated crops but at near maturity, the haulm growth is almost complete and partitioning of photosynthetic

Table 2: Effects of Seed Tubers Treatment with Gibberellic Acid on Days to Physiological Maturity, Average Tuber Number Per Hill and Average Tuber Weight of Potato Plants

Treatments	Days to Physiological Maturity	Average Tuber Number Per Hill	Average Tuber Weight (g)
Control (Ethanol and DDW)	120.00^{a}	7.29^{de}	82.20^{e}
Haulm application of 250 ppm GA_3	118.67^{a}	7.82^{cde}	87.22^{c}
Haulm application of 500 ppm GA_3	119.67^{a}	8.26^{bcd}	88.30^{bc}
Haulm application of 750 ppm GA_3	110.00^{b}	9.16^{ab}	89.62^{ab}
Haulm application of 1000 ppm GA_3	108.00^{b}	10.12^{a}	90.80^{a}
Dipping tubers in 10 ppm of GA_3	120.00^{a}	6.95^{e}	82.85^{e}
Dipping tubers in 20 ppm of GA_3	118.33^{a}	7.63^{cde}	83.64^{e}
Dipping tubers in 30 ppm of GA_3	119.33^{a}	7.46^{cde}	83.77^{de}
Dipping tubers in 40 ppm of GA_3	117.67^{a}	8.07^{bcd}	84.12^{de}
Dipping tubers in 50 ppm of GA_3	118.33^{a}	8.50^{bc}	86.00^{cd}
Mean	117	8.13	85.85
CV (%)	2.8	7.57	1.57
Level of Significance	**	**	**

Means within a column followed by the same letters are not significantly different at the prescribed level of significance. **, ns = significant at 1% and non- significant at 5% probability level, respectively.

products will be more towards stolons, which could explain the high content of sucrose in the stolons of GA_3 treated crops at this stage.

3.3. Tuber Yield Per Hill, Total and Marketable Tuber Yield

Treating seed tubers with GA_3 significantly affected tuber yield per hill, marketable and total yield of the immediate generation of potato (Table **3**). Haulm applications of 750 and 1000 ppm GA_3 increased tuber yield per hill by about 26% and 45%, respectively, as compared to the control (0.56 kg/hill). Compared to the control, total tuber yield per ha increased by about 37% and 48% in response to haulm application of 750 and 1000 ppm GA_3, respectively. Similarly, haulm applications of 750 and 1000 ppm of GA_3 increased marketable tuber yield by about 39% and 48% above the control, respectively. In contrary, dipping of tubers in GA_3 solutions did not show significant variation with untreated tubers and among treatments. The observed yield improvement in response to GA_3 treatment could be attributed to early crop emergence and tuber initiation. In agreement with current investigation, Gemeda *et al*., [29] reported that GA_3 hastened emergence and increased yields of potato tubers. Confirming to this, Allen *et al*. [49] reported that sprouting seed prior to planting results in more rapid emergence and, in some varieties, production of fewer stems so that economic yields can be obtained earlier than from the un-sprouted seed. According to Pavek and Thornton [50], rapid sprout emergence can promote early-season disease resistance in potato shoots and stems. They also found that rapid emergence allows plants to capture solar radiation early in the season, which is important for optimizing final tuber yield and dry matter content. In agreement with the current study, Lovato *et al*. [51] found that due to increased potato seed tuber sprouting following GA_3 treatment, the yield obtained from treated seed was higher than that grown from untreated seed. Alexopoulos *et al*. [38] found that plants that had been treated with GA_3 early in the growth cycle consistently produced more elongated tubers yields than control. In contrast, Sharma *et al*., [39] observed that foliar application of GA_3 caused deformed tubers where some of these were sickle-shaped. Similarly, Jackson and Prat [52] reported that GA_3 promoted stolon growth and caused the tubers to become more elongated and elliptical than normal. Total tuber yield was positively and significantly correlated with average tuber number (r = 0.92**) and tuber weight (r = 0.94**) signifying that GA_3 treatment improved tuber yield by increasing both tuber number and individual tuber size. Number of tubers set per plant or hill largely governs the total tuber yield as the size categories of the potato tubers [50].

Table 3: Effects of Seed Tubers Treatment with Gibberellic Acid on Tuber Yield Per Hill, Total and Marketable Tuber Yield and Total Biomass Yield

Treatments	Tuber Yield Per Hill(kg)	Total Tuber Yield (Tons/ha)	Marketable Tuber Yield (Tons/ha)	Total Biomass Yield (kg/ hill)
Control (Ethanol and DDW)	0.56^{d}	23.08^{d}	21.67^{d}	0.43^{d}
Haulm application of 250 ppm GA_3	0.58^{d}	28.57^{bc}	27.12^{bc}	0.63^{bc}
Haulm application of 500 ppm GA_3	0.58^{d}	29.56^{bc}	28.10^{abc}	0.66^{bc}
Haulm application of 750 ppm GA_3	0.71^{b}	31.61^{ab}	30.04^{ab}	0.73^{b}
Haulm application of 1000 ppm GA_3	0.82^{a}	34.25^{a}	32.14^{a}	0.94^{a}
Dipping tubers in 10 ppm of GA_3	0.62^{cd}	26.16^{cd}	24.73^{cd}	0.55^{cd}
Dipping tubers in 20 ppm of GA_3	0.67^{bc}	27.04^{bcd}	25.61^{bcd}	0.56^{cd}
Dipping tubers in 30 ppm of GA_3	0.60^{cd}	27.04^{bcd}	25.61^{bcd}	0.58^{bc}
Dipping tubers in 40 ppm of GA_3	0.64^{bcd}	27.22^{bcd}	25.78^{bcd}	0.59^{bc}
Dipping tubers in 50 ppm of GA_3	0.68^{bc}	27.22^{bcd}	26.18^{bcd}	0.63^{bc}
Mean	0.65	28.16	26.71	630
CV (%)	6.9	8.57	9.01	12.74
Level of Significance	**	**	**	**

Means within a column followed by the same letters are not significantly different at the prescribed level of significance. **, ns = significant at 1% and non- significant at 5% probability level, respectively.

3.3.1. Total Biomass Yield

Highly significant difference was found among treatments with regard to total biomass yield per hill (Table **3**). The highest biomass yield (0.94 kg/hill) and (0.73 kg/hill) were obtained from haulm applications of 1000 and 750 ppm, respectively, while the lowest (0.43 kg/hill) was obtained from the control treatment. Similarly, dipping treatments of 30, 40 or 50 ppm were significantly different from the untreated tubers but showed equivalent yield among the treatments. The result indicated that total biomass yield increases with increasing the rates of GA_3 application in both haulm application and dipping treatments. The obtained increase in total biomass yield might be due to the effects of GA_3 on enhancing the growth and increasing the photosynthetic products especially total carbohydrates. Consequently, the above ground biomass might receive more nourishment hence helping to develop better vegetative growth as compared to untreated tubers. In line with the current finding, Faten *et al*., [53] reported that GA_3 caused an increase in plant growth expressed as numbers of shoots and/or leaves as well as fresh and dry weight of different plant organs, consequently increased the efficiency of a plant to absorb more nutrition elements, hence increasing their concentration in plant tissues and/or the storage organ in potato. In agreement with this, Sharma *et al*. [39] reported that foliar spray of GA_3 caused an increase in the weights of haulm (stem and leaves), roots and stolons. Furthermore, Alexopoulos *et al*. [38] observed that application of GA_3 30 days after planting increased the mean fresh weight of leaves per plant without significantly affecting biomass yield. Similar investigation by Allen *et al*. [49] indicated that foliar application of GA_3 increased vegetative growth (fresh and dry weights) and the number of tubers per plant grown from true potato seed.

3.3.2. Dry Matter Content and Specific Gravity

Highly significant differences were observed with regard to dry matter content and specific gravity among different GA_3 treatments (Table **4**). Haulm application of GA_3 at a concentration of 750 or 1000 ppm increased dry matter content by about 15% compared to the control. Tuber dry matter content increased by about 13% as compared to the control in response to dipping the seed tuber in 50 ppm GA_3 solution. Regardless of the concentration, haulm application of GA_3 increased specific gravity by about 2% as compared to the control. Similarly, dipping seed tubers in 50 ppm of GA_3 solution increased the tuber specific gravity of the next generation by 1.3% as compared to the control. The increase in dry matter content and specific gravity could be due to the increase in above ground biomass that favors photosynthetic rate and higher dry matter accumulation in the tubers. In accordance with this,

Table 4: Effects of Seed Tubers Treatment with Gibberellic Acid on Tuber Dry Matter Content and Specific Gravity of the Next Generation

Treatments	Dry Matter Content (%)	Specific Gravity (gcm^{-3})
Control (Ethanol and DDW)	21.43^{d}	1.082^{c}
Haulm application of 250 ppm GA_3	24.23^{b}	1.097^{a}
Haulm application of 500 ppm GA_3	24.27^{b}	1.096^{a}
Haulm application of 750 ppm GA_3	24.60^{ab}	1.099^{a}
Haulm application of 1000 ppm GA_3	24.90^{a}	1.099^{a}
Dipping tubers in 10 ppm of GA_3	21.50^{d}	1.082^{c}
Dipping tubers in 20 ppm of GA_3	21.67^{d}	1.082^{c}
Dipping tubers in 30 ppm of GA_3	22.70^{c}	1.089^{b}
Dipping tubers in 40 ppm of GA_3	23.13^{c}	1.091^{b}
Dipping tubers in 50 ppm of GA_3	24.23^{b}	1.096^{a}
Mean	23.27	1.092
CV (%)	1.39	0.16
Level of Significance	**	**

Means within a column followed by the same letters are not significantly different at the prescribed level of significance. **, ns = significant at 1% and non-significant at 5% probability level, respectively.

results found that exogenous GA_3 application increased shoot growth, photosynthesis and dry matter accumulation. In addition, Burton [54] reported that when applied as a spray to foliage, GA_3 increases leaf area and stem growth especially when nitrogen supply is small. In line with the current finding, the author found that the total dry matter may increase because of the increase in leaf area but only temporally. Alexopoulos *et al*. [38] found that application of GA_3 at a more mature stage of plant growth, 60 days after planting, had no effect on tuber dry matter content, since by then tuberization and presumably starch synthesis were virtually complete.

Sharma *et al*. [39] reported that following early haulm application of GA_3 30 days after planting, the supply of sugars to the tubers decreased due to competition as a result of increasing growth of the aerial organs. In the same manner, Alexopoulos *et al*. [38] reported that haulm application of GA_3 30 days after planting reduced the dry matter content of the tubers whereas later application of GA_3 had no effect on the tuber dry matter content. In contrary, Allen *et al*. [49] observed that foliar application of GA_3 to potato plants caused a significant reduction in the dry matter content of tubers. Therefore, the reduction in tuber dry matter content following GA_3 treatment is thought to be due to a reduction in starch content as a result of sucrose retention by the shoots, and restricted sucrose supply to the tubers [39].

In this study, all GA_3 treatments had dry matter content above 23.6% and a specific gravity higher than 1.080 regardless of the method of GA_3 applications, indicating that GA_3 treated seed tubers produced tubers suitable for processing like Chips and French fries making.

Generally, in the present study, for both methods of GA_3 applications, the higher concentration resulted in higher specific gravity and dry matter content compared with the untreated tubers; however, the variation among the treatments were inconsistent. Since the potato variety used in this experiment had a characteristic of late maturing and long dormancy period, high specific gravity and dry matter content is also its common characteristic. This is in agreement with the finding of Burton [54] who reported that the dry matter content of early maturing cultivars is usually lower than that of the late maturing varieties. Moreover, Abebe [20] indicated that specific gravity can indirectly provide a dry matter content estimate, and is also related to the industrial yield, oil absorption during frying, and final product quality. Therefore, the result of the study showed that specific gravity was positively and significantly correlated with dry matter content (r= 0.99**) hence indicating that specific gravity is a true indicator of dry matter content. This is also confirmed by the report of Tekalign and Hammes, [55].

4. CONCLUSION AND RECOMMENDATION

In Ethiopia, potato is one of the most widely used root and tuber crops in human diet. It is also an important cash crop for farmers in the mid and highland parts of the country, where it is grown abundantly. However, the lack of quality planting seed tuber among growers is a limiting factor adversely affecting the production and productivity in potato growing areas of the country. Conversely, identifying appropriate management practices to improve the quality of planting materials is a priority to introduce plant growth regulators for potato producers. The result of this study indicated that, both haulm application and dipping methods of treatments have effect on dormancy break, early emergence of shoots, increased tuber yield and quality of potato.

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