Advances in Crop Science and Technology

Degebasa, Adv Crop Sci Tech 2020, 8:4

Research Article **Open Access**

Role of Different Gibberellic Acid Application Methods and Rates for Potato (*Solanum tuberosum* L.) Tuber Dormancy-Breaking and Subsequent Yield

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Received date: May 01, 2020; **Accepted date:** May 18, 2020; **Published date:** May 27, 2020

Abstract

The production of potato in two or more cycles in a year is increasing in Ethiopia and it is a common practice for potato growers. Thus, it is important to break the long dormancy of tubers for early sprouting and planting. Moreover, lack of good quality seed tuber among growers is a major problem adversely affecting the expansion of potato production in country where land and water is suitable for potato production. Therefore, the experiment was conducted during 2008-2009 cropping season with the objective of determining the effects of different methods and rates of Gibberellic acid (GA_3) application on dormancy break, sprouting, subsequent effect on tuber yield and tuber quality of potato variety, Gera. The experiment consisted of five levels of GA_3 [0, 250,500, 750 and 1000 parts per million (ppm)] as haulm application a week prior to haulm destruction and five levels of GA_3 [10, 20, 30, 40 and 50 parts per million (ppm)] as a dipping treatment immediately after harvest for 24 hrs. Treatments were arranged in Randomized Completed Block Design with three replications in diffused light storage (DLS) till the tubers get sprouted. The result revealed that GA_3 application affects dormancy period and enhanced sprouting characteristics of tubers. Haulm application of GA_3 at 750 and 1000 ppm reduced dormancy period by 24 days and 27 days, respectively. Similarly, dipping treatments of 40 and 50 ppm has reduced dormancy period by 18 days and 20 days, respectively, as compared to the untreated tubers. Moreover, Haulm applications of 750 and 1000 ppm GA_3 increased tuber yield per hill by about 26% and 45%, respectively as compared to untreated tubers. Regardless of the concentration, haulm application of GA_3 increased specific gravity by about 2% as compared to the control. In the same manner, dipping seed tubers in 50 ppm of GA_3 solution increased tuber specific gravity of the next generation by 1.3% as compared to the control. Therefore, the study indicated that both haulm application and dipping treatments of GA_3 could result in early dormancy termination, early emergence of shoots, increased sprout number and yield and yield components.

Keywords: Potato; Dipping treatment; Haulm application; Dormancy; Sprout induction; Specific gravity

Introduction

Globally, potato (*Solanum tuberosum* L.) is the fourth most important cultivated food crop with an overall production of 377 million tonnes fresh-weight in 2016 [1]. It is the third most important food crop in the world after rice and wheat in terms of human consumption [2]. Potato is not only a rich source of carbohydrates but also contains significant amounts of proteins, minerals, vitamins, micronutrients and phytonutrients, including antioxidants, as well as dietary fibre [3]. 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 [4,5]. Estimated potato cultivated area was 160,000 hectares in 2001, while it was reached 0.3 million ha in 2015with production volume of 572,000 ton to 3.66 million tons, respectively [6,7]. Despite the prevailing suitable conditions, potato productivity has remained low with the productivity of 14.18 t/ha still below world average of 19 t/ha [8].

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 [9]. One major problem facing production of quality potato seed is poor sprouting due to dormancy, which leads to delayed planting and poor crop emergence and vigor [10]. Thus, harvested root and tuber crops are living parts of the plant that continue to metabolize and respire after harvest. At harvest and for an intermediate period after harvesting potato tubers are dormant and cannot sprout. Rapid termination of tuber dormancy is desirable for certain segments of the potato industry such as seed certification and re-use of harvested tubers using irrigation [11]. Plant growth regulators (PGR) have considerable effects on tuber fertility and it is highly related to hormonal balance [12,13]. By treating the tubers using gibberellic acid (GA_3), the tubers can be sprouted faster and the tubers treated with GA_3 produce a greater number of seed tubers [14]. Gibberellins are able to break dormancy of potato tubers by sinking (pre-soaking) the seed tubers or spraying the potato plants [15,16]. More buds can be generated per unit area by using GA_3 in potatoes because it can increase the number of stems or stolons in plants [17].

Thus, seed potato tubers planted immediately after harvest is characterized by delayed plant emergence, poor establishment and low yields. Timely availability of well-sprouted seed tubers at the on-set of rain as well as for irrigated potato production is a prerequisite for attaining proper planting materials which leads to high yields. Due to unavailability of sprouted tubers for planting at desired time, smallholder farmers often promote potato sprouting by placing using various traditional practices such as pits, sacks, teff straw and trenches and use genotypes with short dormancy. Under Ethiopian condition, even though several potato varieties were developed so far genotypes short dormancy period and utilization of different chemicals and plant growth regulators to regulate potato dormancy were not common. This is attributed to the lack of information regarding suitable chemicals, methods, rates, and time of application for efficient use. Therefore, this study was conducted to investigate the effect of methods and rates of gibberellic acid on tuber dormancy breaking and subsequent vegetative growth, yield and quality of potato.

Materials and Methods

Description of the study site

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 in central Ethiopia. The daily average minimum and maximum temperatures of the area during the growing seasons 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 Nitisols, which is characteristically reddish to brown in color. It has soil pH of 6.67 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} soil, respectively [18].

Description of experimental materials

Potato cultivar, Gera which is nationally released in 2003 with a yielding potential of 25 tons/ha and having extended dormancy period of more than three months and having large, round and white tubers with deep eyes was used for the experiment.

Treatments and experimental design

The experiment was conducted at Holetta Agricultural Research Centre during June to October, 2008 under rainfed condition and from February to May, 2009 using irrigation. The study consisted of two separate experiments. The first experiment consisted of tuber dormancy breaking study by treating (haulm application and dipping) of tubers with GA_3 and storing them under Diffused Light Store (DLS). The second experiment dealt with subsequent field evaluation of the tubers subjected to GA_3 treatment for subsequent yield and yield components. For both experiments, well sprouted medium-sized potato tubers with approximate weight of 30 to 75 g and with sprout length of 1.5 to 2.5 cm were planted on the ridges at the spacing of 75 cm between ridges and 30 cm between tubers in a row at the depth of about 5-10 cm and were covered with soil [19]. 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 harvest freshly harvested 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 A3 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 treated with ethanol and DDW only for the same duration [20].

Storage trial

To determine the effect of GA3 on dormancy and sprout growth, ten uniform medium sized (35-45 mm) tubers for each treatment (foliar sprayed and dipped) were selected, labeled and stored in a naturally ventilated diffused light store being arranged in a randomized complete block design with three replications. Tubers were monitored every other day and continued until 95% of the tubers get sprouted. During the storage period, the internal temperature and relative humidity of the storage room was recorded every day using thermo-hygrometer. The mean minimum and maximum temperatures in the store were 3.2 °C and 21.3 °C, respectively and the average relative humidity was of 62.4% recorded.

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 re-planted during the off-season in the field using irrigation. The experimental plots of (3 m × 3 m) 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 75 cm × 30 cm between rows and plants, respectively, in four rows having ten plants each. Phosphorus was applied at the rate of 92 kg/ha all at 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 (45 days after planting) as a side dress in the form of Urea. Appropriate cultural practices were applied accordingly to the research recommendation [19]. As a crop protection measure Ridomil® MZ 68% WP was sprayed twice at a rate of 2 kg/ha before the occurrence of late blight to control the disease. Other cultural practices such as cultivation, weeding and earthing up were carried out according to the research recommendation [21]. Dehaulming was done seven days before harvesting to enhance tuber maturity, facilitate harvesting and to reduce peeling of the tubers.

Storage and field trial

For tuber dormancy break and sprouting parameters such as dormancy period, average number of sprouts per tuber, average sprout length (mm), fresh mass of sprout (mg), dry mass of sprout (mg), and weight loss of the tubers was considered. To study the effect of GA_3 treatment on the subsequent growth, tuber yield and quality of potato, a field trial was conducted and evaluated days to emergence, plant height (cm), stem number per plant, days to physiological maturity, average tuber number per plant, average tuber weight (g), tuber yield per plant (g), total tuber yield (tons/ha), marketable tuber yield per plot (tons/ha),biomass yield, harvest index and tuber quality characteristics like tuber dry matter content(%), and specific gravity of tubers (gcm^{-3}) were evaluated.

Statistical data analysis

The data was analyzed using analysis of variance (ANOVA) and treatment means were separated by Least Significant Differences (LSD) at 1% and 5% probability level by using SAS statistical software packages version 9.00 [22].

Results and Discussion

Tuber dormancy break

Dormancy period: Highly significant differences ($p<0.01$) was found among the treatments with regard to tuber dormancy period as indicated in (Table 1). The data showed that all haulm applications and dipping of GA_3 significantly reduced tuber dormancy period below the control with more reduction when the concentration of GA_3 increased. Haulm application of 750 and 1000 ppm GA_3 reduced the duration of tuber dormancy by about 24 and 27 days, respectively after harvesting as compared to control and other treatments. Similarly, tubers treated with 40 and 50 ppm GA_3 solutions reduced the duration of tuber dormancy by about 18 and 20 days, respectively. Moreover, low GA_3 concentration (10 ppm) used as dipping resulted in 8 days of reduction as compared to untreated tubers. In accordance with the current results, Holmes et al. reported that GA_3 treatment immediately after harvesting reduced the duration of tuber dormancy by 38-42 days [23]. These authors indicated that GA_3 is involved in breakage of dormancy and growth stimulation. Dogonadze et al. showed that a haulm application of GA_3 just before haulm destruction, shortened the dormancy period of the harvested seed tubers up to three months [24]. In addition, Alexopoulos et al. found that post-harvest application of GA_3 to tubers grown from seed potatoes promotes the breakage of dormancy. Coleman also described that exogenous GA_3 generally terminate dormancy in potatoes and may play important roles as endogenous regulators of bud dormancy and development [25]. In addition, Martin et al. found that, foliar application of GA_3 alone or GA+BA resulted in significant decrease in duration of subsequent tuber dormancy period and sprouting and this varied among the genotypes [26].

Treatments	**Dormancy period (days)**	**Average sprout number per tuber**	**Average sprout length (mm)**
Control (Ethanol and DDW)	106.00^{a}	2.00^{d}	48^{d}
Haulm application of 250 ppm GA_3	94.67^{b}	4.00^{abc}	80^{b}
Haulm application of 500 ppm GA_3	85.33^{cd}	4.00^{abc}	90^{a}
Haulm application of 750 ppm GA_3	82.33^{de}	4.33^{ab}	92^{a}
Haulm application of 1000 ppm GA_3	79.00^{e}	5.33^{a}	93^{a}
Dipping tubers in 10 ppm of GA_3	98.33^{b}	2.67^{cd}	55^{d}
Dipping tubers in 20 ppm of GA_3	97.67^{b}	3.00^{bcd}	70^{c}
Dipping tubers in 30 ppm of GA_3	95.67^{b}	3.33^{bcd}	80^{b}
Dipping tubers in 40 ppm of GA_3	87.67^{c}	3.67^{bc}	86^{ab}
Dipping tubers in 50 ppm of GA_3	86.00^{cd}	4.00^{abc}	88^{a}
Mean	91.27	3.63	78
CV (%)	2.34	20.58	5.31
Level of Significance	**	**	**

Note: Means within a column followed by the same letters are not significantly different at the prescribed level of significance. **: Significant at 1% probability level; LSD (0.05): Least significant difference at 0.05 probability level; CV (%): Coefficient of variation in percent.

Table 1: Effects of treating seed tubers with gibberellic acid on length of dormancy period, average sprout number and length of potato tuber.

Average number of sprout per tuber: Highly significant differences ($p<0.01$) was found among treatments with regard to the number of sprout per tuber as presented in (Table 1). Regardless of the concentration, all haulm application treatments and dipping of tubers in 40 and 50 ppm GA_3 gave significantly higher sprout number as compared to the control. In line with the current investigation, Coleman reported that, sprout number of tubers from plants sprayed with a high GA_3 concentration was significantly higher than that of tubers from control plants [25]. Similarly, Kim et al. found that irrespective of the concentration, GA_3 treatments (1, 5, 10 and 50 mg/l) significantly increased the number of sprouting buds per tuber compared to the control [27]. GA_3 treatments increase the number of sprouts; the length of the sprouts and proportion of sprouts by about 10 percent [28-32]. Similarly, Shibairo et al. showed that increase in GA_3 concentration led to increase in sprouting percentage, number of sprouts per tuber, sprout length and sprout vigor [33].

Average sprout length: Average sprout length per tuber was significantly ($p<0.01$) influenced by GA_3 treatments (Table 1). Applications of GA_3 at a rate of 500, 750 or 1000 ppm increased sprout length by about 91% as compared to the control, 48 mm long. Similarly, in reference to the control (48 mm long) about 83% sprout length increment was obtained in response to dipping of the tubers in 40 or 50 ppm GA_3 solution. The data revealed that both haulm application and dipping treatment with GA_3 showed increasing trend of sprout length with increasing the rate of GA_3. In agreement with current results, Caldiz observed that the mean sprout length per tuber following treatment with GA_3 or GA_3+BA was significantly higher than that of the controls [21]. Similarly, Alexopoulos et al. showed that sprout length on seed tubers increases by exogenous application of

GA_3 [29]. In addition, Sharma et al. reported that mini-tubers treated with GA_3 were effective in increasing the length of sprouts [31]. Thus, GA_3 treatments resulted in high sprout growth rates possibly due to an increase in assimilate flow towards the growing sprouts.

Fresh and dry mass of sprouts: Highly significant difference ($p<0.01$) were found among treatments with regard to fresh and dry mass of sprout per tuber (Table 2). Haulm application of GA_3 at 1000 ppm resulted in the highest fresh mass (1040 mg) of sprout which was 103% more as compared to the control. In the same way, foliar spray of GA_3 at a rate of 500, 750 or 1000 ppm and dipping in 50 ppm of GA_3 brought about 78% and 52% dry sprout mass increment compared to the control (112 mg). In agreement to this study, Verma found that the fresh weight of sprouts per tuber following treatment with GA_3 or GA_3+BA was significantly higher than that of the controls. Therefore, it seems that increased concentration of GA_3 treatment increased growth of sprouts per tuber and also the rate of transfer of dry matter from tuber to sprout and finally improved sprout dry matter. In the current study, fresh and dry mass of sprouts were positively and significantly correlated with average sprout number ($r=0.97^{**}$; $r=0.81^{**}$) and sprout length ($r=0.98^{**}$; $r=0.86^{**}$) indicating that GA_3 treatment increased sprout mass by increasing both sprout number and length.

Treatments	Fresh mass of sprout per tuber (mg)	Dry mass of sprout per tuber (mg)	Percentage weight loss per tuber (%)
Control (Ethanol and DDW)	510^{e}	112^{c}	58.2^{f}
Haulm application of 250 ppm GA_3	750^{bcd}	174^{b}	71.5^{cd}
Haulm application of 500 ppm GA_3	780^{bc}	182^{ab}	75.2^{bc}
Haulm application of 750 ppm GA_3	820^{b}	191^{ab}	78.7^{b}
Haulm application of 1000 ppm GA_3	1040^{a}	224^{a}	92.8^{a}
Dipping tubers in 10 ppm of GA_3	600de	145^{bc}	62.5^{ef}
Dipping tubers in 20 ppm of GA_3	630^{cde}	149^{bc}	66.5^{de}
Dipping tubers in 30 ppm of GA_3	640^{cde}	150^{bc}	70.0^{cd}
Dipping tubers in 40 ppm of GA_3	730^{bcd}	170^{b}	70.5^{cd}
Dipping tubers in 50 ppm of GA_3	730^{bcd}	171^{b}	71.3^{cd}
Mean	720	170	71.7
CV (%)	12.09	14.77	4.81
Level of Significance	**	**	**

Note: Means within a column followed by the same letters are not significantly different at the prescribed level of significance. **: Significant at 1% probability level; LSD (0.05): Least significant difference at 0.05 probability level; CV (%): Coefficient of variation in percent.

Table 2: Effects of seed tubers treatment with gibberellic acid on sprout fresh and dry mass, and weight loss percentage of tubers.

Percentage weight loss of tubers: Highly significant differences ($p<0.01$) was found among treatments with regard to percentage weight loss of the tubers (Table 2). This parameter was significantly higher in the tubers treated with 1000 ppm (92.8%) followed by 750 ppm (78.7%) of GA_3 as compared to the control (58.2%). In the present study, tubers weight loss may be due to water loss, utilization of reserve carbohydrates by newly emerging sprouts and respiration of mother tubers. In agreement with this study, Sharma et al. reported that GA_3 treated tubers showed significantly higher weight loss as compared to untreated tubers [31]. The authors described that, the higher weight loss in GA_3 treated tubers in the first 7 days after treatment could be attributed to the incisions made to facilitate the entry of GA_3. Similarly, Vreugdenhil et al. indicated that sprouting is accompanied by many physiological changes including increases in reducing sugar content, respiration, water loss, and glycol alkaloid content and also mentioned that GA_3 increased the rate of weight loss as compared to untreated tubers [17,31]. The higher weight loss in GA_3 treated tubers may be due to the higher rate of metabolism which is associated with sprout initiation and growth [34].

Vegetative growth, yield and quality parameters

Days to emergence: Highly significant differences ($p<0.01$) was found among treatments with regard to days to emergence of the shoots (Table 3). Both haulm applications and dipping treatments of GA_3 significantly reduced days to emergency 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 emergency 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 finding, Timm et al. 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 [35]. GA_3 applied as a foliar spray induced earlier sprouting of the subsequently harvested tubers [36]. Tuber treatment with GA_3 enhanced sprout growth and resulted in faster emergence in potato [37,38].

Treatments	Days to emergency	Plant height (cm)	Days to physiological maturity
Control (Ethanol and DDW)	34.00^{a}	82.50^{f}	120.00^{a}
Haulm application of 250 ppm GA_3	27.00^{bc}	86.25^{cd}	118.67^{a}
Haulm application of 500 ppm GA_3	24.67^{de}	87.33^{bc}	119.67^{a}
Haulm application of 750 ppm GA_3	23.33^{ef}	88.58^{ab}	110.00^{b}
Haulm application of 1000 ppm GA_3	22.67^{f}	89.83^{a}	108.00^{b}
Dipping tubers in 10 ppm of GA_3	28.67^{b}	83.52^{ef}	120.00^{a}
Dipping tubers in 20 ppm of GA_3	27.33^{bc}	83.75^{ef}	118.33^{a}
Dipping tubers in 30 ppm of GA_3	27.67^{bc}	83.92^{ef}	119.33^{a}
Dipping tubers in 40 ppm of GA_3	28.33^{b}	84.75^{de}	117.67^{a}
Dipping tubers in 50 ppm of GA_3	26.33^{cd}	85.70^{cd}	118.33^{a}
Mean	27	85.61	117
CV (%)	3.89	1.13	2.8
Level of Significance	**	**	**

Note: 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

Table 3: Effects of seed tubers treatment with gibberellic acid on days to emergence, plant height and days to physiological maturity of potato plants.

Plant height: Seed tuber treatment with GA_3 significantly (p<0.01) influenced plant height of the immediate generation of potato as presented in (Table 3). 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 untreated tubers. In favor of the current finding, Alexopoulos et al. and Sharma et al. 1998observed an increase in plant height, number of nodes and internodes length when GA_3 was applied at 60 days after planting [29,31]. According to Alexopoulos et al. GA_3 treatment has increased the plant height by increasing both internodes length and number of nodes per plant [30]. Alexopoulos et al. observed that foliar application of GA_3 to potato plants derived from true potato seed caused an increase in plant height similar to that reported for potato plants from seed tubers [30]. In the same manner, Sharma et al. found that single application of $GA_3$to potato plants derived from true potato seed caused an increase in plant height similar to that reported for potato plants derived from seed tubers [31]. Similarly, Struik et al. from their study conducted on soil application of various concentration 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 [32].

Days to physiological maturity: Highly significant difference (p<0.01) 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 3). 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 emergency of shoots. In supporting this view, (Verma, 1966) reported that tubers having shorter dormancy period senesces earlier, and produces more tubers but of smaller size. In addition, Caldiz examined that leaves from GA3 sprayed potato plants showed pale-green and early senescence than the untreated control plants [21].

Average tuber number: Highly significant difference (p<0.01) was found among treatments with regard to average tuber number per hill (Table 4). 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 at par. This indicates that number of tubers initiated by individual plant could be influenced by the GA_3 treatments which could be by affecting stolon initiation and branching[39]. In favor of this view Alexopolus et al. 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 [40]. The author also showed that foliar applied GA_3 significantly increased tuber number either if applied alone or in combination with cytokinins, while no effects of cytokinins alone were found. Similarly, Holmes et al. reported 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 Timm et al. [23,35]. The increase in average tuber number might be due to the increased photosynthetic activity and translocation of photo synthate to the root, which might help in the initiation of more stolon in potato according to Lippert et al. [36]. Rehmanet al. reported that when plants were treated once with GA_3 early in their growth cycle, the number of tubers per plant increased, but this effect is critically dependent on the time of application Lim et al. [38]. 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 El-Gizawy et al.[39].

In agreement with this study, Ezekiel et al. 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 [28]. Alexopoulos et al. found that, haulm application of GA_3 at 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 application is repeated [30,40]. Alexopoulos et al. 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. [32].

Average tuber weight: Highly significant difference (<0.01) was observed among treatments with regard to average tuber weight (Table 4). Haulm applications of 750 or 1000 ppm GA_3 improved average tuber weight by almost 10% in reference to the control (82.20 g). Dipping tubers in 50 ppm of GA_3 solution increased average tuber weight from 82.20 g to 86 g bringing almost 5% increment. An increase in 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 finding, Struik et al. 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 [32]. Average tuber weights in potato has been reported to be the most important yield component known to significantly influence total tuber yield [27].

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. exogenous GA_3 is known to decrease tuber weight and tuber to shoot ratio [31]. The authors described that at early stages of development, there is rapid haulm growth of GA_3 treated crops but, at near maturity, haulm growth is almost complete and partitioning of photosynthetic 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.

Treatments	**Days to emergency**	**Plant height (cm)**	**Days to physiological maturity**
Control (Ethanol and DDW)	34.00^{a}	82.50^{f}	120.00^{a}
Haulm application of 250 ppm GA_3	27.00^{bc}	86.25^{cd}	118.67^{a}
Haulm application of 500 ppm GA_3	24.67^{de}	87.33^{bc}	119.67^{a}
Haulm application of 750 ppm GA_3	23.33^{ef}	88.58^{ab}	110.00^{b}
Haulm application of 1000 ppm GA_3	22.67^{f}	89.83^{a}	108.00^{b}

Dipping tubers in 10 ppm of GA_3	28.67^{b}	83.52^{ef}	120.00^{a}
Dipping tubers in 20 ppm of GA_3	27.33^{bc}	83.75^{ef}	118.33^{a}
Dipping tubers in 30 ppm of GA_3	27.67^{bc}	83.92^{ef}	119.33^{a}
Dipping tubers in 40 ppm of GA_3	28.33^{b}	84.75^{de}	117.67^{a}
Dipping tubers in 50 ppm of GA_3	26.33^{cd}	85.70^{cd}	118.33^{a}
Mean	27	85.61	117
CV (%)	3.89	1.13	2.8
Level of Significance	**	**	**

Note: 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.

Table 4: Effects of seed tubers treatment with gibberellic acid on average tuber number per hill, average tuber weight and tuber yield per hill of potato plants.

Tuber yield per hill, total and marketable tuber yield: Treating seed tubers with GA_3 significantly ($p<0.01$) affected tuber yield per hill, marketable and total yield of the immediate generation of potato (Table 4). 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 (562.80 g). 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 Lim et al. reported that GA_3 hastened emergence and increased yields of potato tubers [38]. Confirming to this, Allen et al. 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 un-sprouted seed [41]. According to Paveket al. rapid sprout emergence can promote early-season disease resistance in potato shoots and stems [42]. 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. 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 [43]. Alexopoulos et al. found that plants that had been treated with GA_3 early in the growth cycle consistently produced more elongated tubers yields than control [30]. In agreement with current study, Martin et al. described that, GA_3 enhances vegetative growth; average number of stems, leaflets number and more yields [26]. More sprouts per tuber may result in more stems per plant. Consequently, more stems per plant results more leaves, and the ground cover taking place at a faster rate of ground cover, higher amount of intercepted radiation and assimilation and hence higher total yields.

In contrast, Sharma et al. observed that foliar application of GA_3 caused deformed tubers where some of these were sickle-shaped [31]. Similarly, Jackson et al. reported that GA_3 promoted stolon growth and caused the tubers to become more elongated and elliptical than normal [44]. 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 [42].

Treatments	**Total tuber yield (tons/ha)**	**Marketable tuber yield (tons/ha)**	**Total biomass yield (g/hill)**
Control (Ethanol and DDW)	23.08^{d}	21.67^{d}	430.00^{d}
Haulm application of 250 ppm GA_3	28.57^{bc}	27.12^{bc}	630.00^{bc}
Haulm application of 500 ppm GA_3	29.56^{bc}	28.10^{abc}	656.67^{bc}
Haulm application of 750 ppm GA_3	31.61^{ab}	30.04^{ab}	733.33^{b}
Haulm application of 1000 ppm GA_3	34.25^{a}	32.14^{a}	936.67^{a}
Dipping tubers in 10 ppm of GA_3	26.16^{cd}	24.73^{cd}	553.33^{cd}
Dipping tubers in 20 ppm of GA_3	$27.04b^{cd}$	25.61^{bcd}	556.67^{cd}
Dipping tubers in 30 ppm of GA_3	$27.04b^{cd}$	25.61^{bcd}	580.00^{bc}
Dipping tubers in 40 ppm of GA_3	$27.22b^{cd}$	25.78^{bcd}	596.67^{bc}
Dipping tubers in 50 ppm of GA_3	$27.22b^{cd}$	26.18^{bcd}	626.67^{bc}
Mean	28.16	26.71	630
CV (%)	8.57	9.01	12.74
Level of Significance	**	**	**

Note: 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

Table 5: Effects of seed tubers treatment with gibberellic acid on tuber yield per hill, total and marketable tuber yield, total biomass yield and harvest index.

Total biomass yield: Highly significant difference ($p<0.01$) was found among treatments with regard to total biomass yield per hill (Table 5). The highest biomass yield (936.67 g) and (733.33 g) were obtained from haulm applications of 1000 and 750 ppm, respectively while the lowest (430 g) was obtained from the control treatment. Similarly, dipping treatments of 30, 40 or 50 ppm significantly different from untreated tubers but at par 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 helping to develop better vegetative growth as compared to untreated tubers. In line with the current finding, Faten et al. 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 plant to absorb more nutrition elements, hence increase their concentration in plant tissues and/or the storage organ in potato [45]. In agreement with this, Sharma et al. reported that foliar spray of GA_3 caused an increase in the weights of haulm (stem and leaves), roots and stolon's [31]. Furthermore, Alexopoulos et al. observed that application of GA_3 at 30 days after planting increased the mean fresh weight of leaves per plant without significantly affecting biomass yield [30]. Similar investigation by El-Gizawy et al. revealed 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 [39].

Dry matter content and specific gravity: Highly significant differences (p<0.01) was observed with regard to dry matter content and specific gravity among different GA_3 treatments (Table 6). 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 result Dyson found that exogenous GA_3 application increased shoot growth, photosynthesis and dry matter accumulation [46]. In addition, Burton, reported that when applied as a spray to foliage, GA_3 increases leaf area and stem growth especially when nitrogen supply is small [15].

In line with the current finding, the author found that total dry matter may increase because of the increase in leaf area but only temporally. Alexopoulos et al. found that application of GA_3 at a more mature stage of plant growth, at 60 days after planting had no effect on tuber dry matter content, since by then tuberization and presumably starch synthesis was virtually complete [30]. Sharma et al. found that, following early haulm application of GA_3 at 30 days after planting, the supply of sugars to the tubers decreases due to competition as a result of increasing growth of the aerial organs [31]. In the same manner, Alexopoulos et al. reported that haulm application of GA_3 at 30 days after planting reduced the dry matter content of the tubers whereas later application of GA_3 had no effect on tuber dry matter content [30]. In contrary, El-Gizawy et al. observed that foliar application of GA_3 to potato plants caused a significant reduction in the dry matter content of tubers [39]. 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 [31].

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	**	**

Note: 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.

Table 6: Effects of seed tubers treatment with gibberellic acid on tuber dry matter content and specific gravity of the next generation.

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 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 Schippers, who reported that the dry matter content of early maturing cultivars is usually lower than that of the late maturing varieties [47]. Moreover, Dyson, indicated that, specific gravity can indirectly provide a dry matter content estimate, and is also related to industrial yield, oil absorption during frying, and final product quality [46]. Therefore, the result of study showed that specific gravity was positively and significantly correlated with dry matter content ($r=0.99^{**}$) indicating that specific gravity is a true indicator of dry matter content. This also confirmed by the report of Tekalign et al. [48].

Conclusion and Recommendation

Potato is a versatile food crop and a source of cheap human diet and has multi nutritional value in many countries. The production of potato for two or more cycles in a year is a common practice by potato growers and the trend also increasing throughout 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 since long shelf life of tubers is an advantage for farmers and consumers for long period consumption and sale. However, the improved potato varieties are failed to fit for the existing practice of two or more cycles of production in a year. Moreover, lack of quality planting materials 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 methods of treatments have effect on dormancy breaking, early emergence of shoots, increased tuber yield and quality of potato. Haulm applications of GA_3 at 750 and 1000 ppm reduced dormancy period by 24 and 27 days, respectively. Similarly, dipping treatment of 40 and 50 ppm reduced dormancy period by 18 and 20 days, respectively and had more effect over the control than lower concentrations. Both haulm application of 750 or 1000 ppm and dipping of 40 and 50 ppm reduced days to emergence. The fresh and dry mass of sprouts were positively and significantly correlated with average sprout number and sprout length indicating that GA_3 treatment increased sprout mass by increasing both sprout number and length. The present result showed that increase in GA_3 concentration led to increase in sprouting percentage, number of sprouts per tuber, sprout length and sprout vigor. Similarly, increasing GA_3 concentrations increased sprouting percentage, number of sprouts per tuber and sprout length. Moreover, dipping tubers in 50 ppm of GA_3 solution increased average tuber weight. The total tuber yield was positively and significantly correlated with average tuber number and tuber mass signifying that GA_3 treatment improved tuber yield by increasing both tuber number and individual tuber size. Due to the increase in tuber size, increased number of tuber per hill and heavy tubers at the increased level of GA_3 the current result recorded large number of marketable and total yield. Foliar application of GA_3 late in the growth cycle may be of practical value in cases where tubers are required for planting soon after harvest especially using irrigation. Therefore, higher doses of GA_3were recommended for foliar application than dipping treatments. Although the experiment was conducted in one location and season using a single cultivar it is reasonable to point out that, foliar applications of gibberellic acid one week before harvest resulted in shortened dormancy period and improved both yield and quality of the subsequent potato generation.

Acknowledgements

The author would like to acknowledge the Ethiopian Institute of Agricultural Research and the Holetta Agricultural Research Center for the financial support and facilitations during this study. The author is also grateful for technical and support staffs who have contributed for the success of the study.

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