Yield and Yield Components of Potato (*Solanum tuberosum* L.) as affected by Plant Growth Regulators and Potato Varieties at Kulumsa Agricultural Research Centre, Southeastern Ethiopia

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ABSTRACT

Potato tuberization is influenced by environmental factors like light intensity, photoperiod and temperature. Changes in these factors influence the levels of endogenous plant growth regulators. The present study was done at Kulumsa Agricultural Research Centre (KARC), Southeastern Ethiopia during the main cropping season of 2018 to determine the effect of three plant growth regulators (PGRs) (Gibberellic acid-GA_3, Benzyl aminopurine-BAP and Benzyl adenine-BA) on yield and yield components of two potato varieties (Belete and Jalenie). Forty sprouted seed tubers with pre-treatment of the three PGRs at different concentrations were planted per plot ($9m^2$) using the recommended spacing of 75cmx30cm in an experiment using Randomized Complete Block Design (RCBD) with three replications. BAP and BA significantly ($P<0.05$) affected the yield and yield components of potatoes such as tuber weight, leaf area index, marketable and total tuber yield per hectare and these results were better than the effects due to GA_3 and distilled water (control). BA at low concentration (0.1mM) increased the average tuber weight over the control by 62.80%; however, BAP increased the average tuber weight at 0.2mM over the control by 59.17%. BAP and BA at 0.1mM concentration increased the leaf area index by 54.81% and 52.9%, marketable tuber yield by 67.28% and 70.55%, and total tuber yield by 61.98% and 65.81% respectively over the control. With the current findings, BAP and BA at the lowest concentration (0.1mM) concentration could be used to pre-treat seed tubers to obtain better tuber yield and yield components.

Keywords: Plant Growth Regulators, yield and yields components potato varieties

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the world's third most important food crop in overall production after rice and wheat and is a food security tuber crop (Devaux *et al*., 2014). From the tuber and root crops potato ranks first in volume produced and consumed followed by Cassava, Sweet potato and Yam in Ethiopia (CSA, 2015). It comprises all essential constituents like carbohydrates, essential nutrients, protein, vitamins, and minerals (Sriom *et al*., 2017). The food potential of horticultural crops, particularly that of root and tuber crops, has not yet been fully exploited and utilized despite their significant contributions towards food security, income generation, provision of food energy and resource base conservation (Gebremedhin *et al*., 2008). About 70% of the available agricultural lands is located at an altitude of 1500-3000 meter above sea level and receives an annual rainfall between 600-1200mm, which is suitable for potato production (Gebremedhin *et al*., 2008). Global production of potatoes was 388 million tons, led by China with 64% of the world total. China is now the biggest potato producer, and almost a third of all potatoes are harvested in China and India (FAOSTAT, 2019). Secondary producers were Algeria and Nigeria while the current average potato productivity in Africa has been reported to be about 13.22 t ha^{-1} which is well below the maximum productivity of 20.11 t ha^{-1}

(FAOSTAT, 2019). The average yield of potato in Ethiopia ranges only between 8 to 10 t ha^{-1}, which is much lower than the yields obtained in the Sudan (17 t ha^{-1}) and Egypt (26 t ha^{-1}) (Haverkort *et al*., 2012).

Shortage of good quality seed tubers of improved cultivars, disease and pests, and lack of appropriate agronomic practices are amongst the factors contributing to the low productivity of potatoes in Ethiopia (Berga *et al*., 1994; Nigussie *et al*., 2012). In addition to those factors plant growth regulators (hormones) have significant roles to enhance potato productivity and quality attributes through influencing tuberization (Jackson, 1999). Potato tuberization is influenced by environmental factors like temperature, photoperiod and light intensity. Changes in these factors influence the levels of endogenous plant growth regulators. Integration of Plant Growth Regulators in potato tuber crop production are among the options of improving crop production. Cutter's (1992) model for the role of PGR in potato tuberization proposes that gibberellins inhibit and abscisic acid promotes tuber induction. Auxins and cytokinins influence tuber size, whereas ethylene inhibits tuber induction in vivo or may cause the swelling of stolon without starch in vitro (Mingo-Castel *et al*., 1976). GA_3 has been reported to have a consistent delaying or inhibiting effect on potato tuberization (Koda and Okazawa, 1983; Abdala *et al*. 1995). However, nowadays some PGRs including cytokinins and gibberellins are widely used to enhance dormancy breaking and to improve the yield and quality of potato tubers globally, however its applicability has not been well studied and practiced in Ethiopia. With this view of the importance of plant growth regulators (PGRs), the present study was conducted with the objective to evaluate the effect of plant growth regulators on the yield and yields components of potato varieties.

The Productivity of Potato is constrained by multidimensional factors such as lack of disease resistant and high yielding varieties with desirable market qualities, limited knowledge of agronomic and crop protection management technologies, and poor post-harvest handling (Nigussie *et al*., 2012).

MATERIALS AND METHODS

Description of the Study Area

The experiment was conducted at Kulumsa Agricultural Research Center (KARC), which is located at 8^{o}00'-8^{o}02'N latitude and 39^{o}07'-39^{o}10'E longitude at an elevation of 2210 m.a.s.l in the year 2018 in Arsi Administrative Zone of the Oromia Regional State, 167 km Southeast of Addis Ababa Ethiopia. Its annual total rainfall is 828 mm and the main season receives 535 mm. The mean annual minimum and maximum temperatures are 9.12 and 22.2°C, respectively. The coldest month is December whereas March and May are the hottest months (Abayneh *et al*., 2003).

Experimental Procedures

Preparation of experimental materials and working samples

Medium sized (35-45mm in diameter) freshly harvested tubers of two common potato varieties (Jalenie and Belete) were obtained from Holetta Agricultural Research Center, West Shoa, Ethiopia. Depending on the physicochemical properties of the three PGRs (Gibberellic acid -GA_3, Benzyl aminopurine-BAP and Benzyl adenine-BA), stock solutions were prepared according to Alexopoulos *et al*. (2007) with modifications. 1000mg GA_3 was dissolved in 50ml ethanol; while 1000mgBAP and 1000mgBA were dissolved in 50ml NaOH each. BAP and BA were slightly warmed to increase the activity of the effectiveness. The final volume was made up to 100ml with distilled water (DW). In order to ensure complete dissolving of the PGRs, an Erlenmeyer flask was filled with 1000ml of distilled water placed on shaker. Working solutions were prepared by diluting appropriate amount of the stock solution with distilled water. Two concentrations of 0.1 and 0.2mM of GA_3, BAP, BA and the untreated control (DW) were prepared for the treatment applications. Forty tubers from each variety were washed with tap water to remove the soil and foreign material adhered to the skin and dried up. The tubers were then soaked with each working solution of the three PGRs for 24 hrs. and for the control treatment with distilled water (DW). Following 24 hrs. soaking, tubers were briefly washed with distilled water and the water from the surface of the tubers was drained off and the experimental tubers were labeled and stored in a diffused light store (DLS) until dormancy was broken and 80% of the tubers showed visible sprouting (~2mm) before used as a seed source for the field experiment.

Treatments and experimental design

Sprouted tubers from each treatment combination (two varieties and three PGRs at two concentrations with untreated control-DW) were arranged as treatments in a factorial experiment using Randomized Complete Block Design (RCBD). Forty sprouted tubers from each treatment combination were planted per plot ($9m^2$) with spacing of 75cm (inter-row) x30cm (intra-row) and treatments were replicated three times. Diammonium Phosphate (DAP) as a source of phosphorus and Urea as a source of nitrogen were applied at a rate of 195 and165 kg ha^{-1}, respectively, following previous recommendations (Abayneh *et al*., 2003). The DAP was applied once at planting, below the tubers, while the urea was applied in splits, half at planting and half at full emergence, (45 days after planting), as a side dress. Appropriate cultural practices were exercised according to previous recommendations given by Berga *et al*. (1994). Ten days before harvesting the haulm was removed in order to enhance tuber maturity, facilitate harvesting and reduce peeling off the tubers. Late blight disease on the experimental plots was managed with Ridomil Gold MZ and Mancozeb fungicides. Each experimental plot was harvested at maturity.

Data Collection and measurements

Leaf area index (LAI) was determined from five randomly selected plants per plot. Individual leaf area of the plants was estimated from individual leaf length using the formula developed by Firman and Allen (1989) and, the LAI was then determined by dividing the total leaf area of a plant by the ground area covered by the plant (Log 10(leaf area in cm^2) = 2.06 x log10 (leaf length in cm)-0.458. **Average tuber weight (g/tuber)** was determined by dividing the total fresh tuber yield of five randomly selected plants per net plot to the respective total number of tubers. **Marketable tuber yield (ton/ha)** was computed from tubers which had on average 25g in size and free from disease and insect pests and then the **total tuber yield (ton/ha)** was calculated as the sum of the weights of marketable and unmarketable tubers from the net plot area and converted to hectare.

Statistical Analysis

The data were subjected to analysis of variance using Gen Stat, 13th Edition (VSN Ltd, Oxford UK) statistical software package. Least significant difference (LSD) test at 5% probabilities was used to separate means when the analysis of variance indicated the presence of significant differences among treatments.

RESULTS AND DISCUSSION

Table 1. Effect of plant growth regulators on average tuber weight of two potato varieties at different concentrations

Average Tuber Weight (gm/tuber)			
Variety	**Gibberellic acid (GA_3)**		
	(DW) control	**0.1mM**	**0.2mM**
Belete	56.44^{bcde}	43.26^{defg}	53.09^{cdef}
Jalenie	36.56^{efg}	29.67^{fg}	24.70^{g}
	Benzyl aminopurine (BAP)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	56.44^{bcde}	72.83^{abc}	81.80^{ab}
Jalenie	36.56^{efg}	52.97^{cdef}	45.35^{defg}
	Benzyl adenine (BA)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	56.44^{bcde}	95.29^{a}	66.62^{bcd}
Jalenie	36.56^{efg}	41.00^{defg}	30.53^{efg}
LSD (5%)		**26.30**	
CV (%)		**30.00**	

Means followed by the same letter(s) within columns and rows are not significantly different at 5% level of probability.

Average tuber weight (g/tuber) was significantly ($P<0.05$) differed among treatments due to plant growth regulators, concentration, potato varieties and their interactions (Table 1). The highest average tuber weight (95.29g) was obtained from Benzyl adenine (BA) treatment at 0.1mM concentration which was 74% higher than the result obtained from treatment of Gibberellic acid (24.7g) on variety Jalenie at 0.2mM. Increment in average tuber weight was also observed on both varieties due to treatment of tubers with Benzyl aminopurine (BAP) when the concentration increased from 0.1mM to 0.2mM. However, unlike BAP and BA, GA_3 reduced the average tuber weight with increased concentration.

Table 2. Interaction effect of plant growth regulators at different concentrations on tuber dormancy and number of sprouts per tuber of two potato varieties

Variety	Dormancy Breaking period (DBP)			Number of Sprout per Tuber (NSPT)		
	Gibberellic acid (GA_3)			Gibberellic acid (GA_3)		
	DW (control)	**0.1mM**	**0.2mM**	**DW (control)**	**0.1mM**	**0.2mM**
Jalenie	142.7	70.3	54.7	4.83a	5.36a	5.23a
Belete	155.0	90.0	92.3	1.93c	4.93a	5.36a
	Benzyl aminopurine (BAP)			**Benzyl aminopurine (BAP)**		
	DW (control)	**0.1mM**	**0.2mM**	**DW (control)**	**0.1mM**	**0.2mM**
Jalenie	142.7	129.3	133.3	4.83a	4.76a	4.23a
Belete	155.0	153.3	155.0	1.93c	2.63c	2.43c
	Benzyl adenine (BA)			**Benzyl adenine (BA)**		
	DW (control)	**0.1mM**	**0.2mM**	**DW (control)**	**0.1mM**	**0.2mM**
Jalenie	142.7	135.7	140.3	4.83a	4.53a	4.10ab
Belete	155.0	145.0	151.7	1.93c	1.86c	2.83bc
LSD (5%)	9.46			1.271		
CV (%)	4.5			19.3		

Means followed by the same letter(s) within columns and rows are not significantly different at 5% level of probability.

Treatment of tubers with the PGRs specifically GA_3 increased number of sprouts per tuber with increased concentration (Table 2), and this increased the number of tubers per hill which definitely reduced the average tuber weight due to competition among tubers for different resources. Regardless of the PGRs used in the present study, Belete scored higher average tuber weight (56.44g) than Jalenie (36.56g), which was genetic differences between the varieties as Belete has got higher tuber size than Jalenie. Barani *et al.* (2013) reported that the effect of GA_3 could be ascribed for its effect on removing apical dominance, which leads to an increase in the number of stolons that would produce increased number of buds, with small sized tubers. Using exogenous cytokinin (BA and BAP), the number of tubers has been increased through enhancing the process of tuberization, which could have effect on tuber weight as well as tuber yield per unit area (Tovar *et al.*, 1985; Ewing and Struik, 1992; Pavlista and Gall, 2010).

Table 3. Effect of plant growth regulators on leaf area index of two potato varieties at different concentrations

	Leaf Area Index (LAI)		
Variety	**Gibberellic acid (GA_3)**		
	(DW) control	**0.1mM**	**0.2mM**
Belete	1.22^{cd}	1.32^{bc}	1.31^{bc}
Jalenie	1.01^{e}	1.16^{cde}	1.11^{de}
	Benzyl aminopurine (BAP)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	1.22^{cd}	1.48^{a}	1.28^{bc}
Jalenie	1.01^{e}	1.06^{e}	1.06^{e}
	Benzyl adenine (BA)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	1.22^{cd}	1.37^{ab}	1.39^{ab}
Jalenie	1.01^{e}	1.01^{e}	1.04^{e}
LSD (5%)		**0.20**	
CV (%)		**7.80**	

Means followed by the same letter(s) within columns and rows are not significantly different at 5% level of probability.

Plant growth regulators (PGRs) significantly ($P<0.05$) affected the leaf area index (LAI) of both varieties (Table 3). The analysis of variance showed that BAP and BA increased the LAI more than the increment due to GA_3 and control (DW). BAP and BA with 0.1mM increased the LAI of Belete variety by 54.81% and 52.9% respectively over the control (DW). Nevertheless, significant difference was not obtained between the effects of BA and BAP on LAI of both varieties although differences were observed between the varieties regardless of PGRs. Martin *et al.,* (2015) reported increased LAI of potato plants grown for seed production from treated seed tubers or foliar application of plant growth regulators. Kedir (2016) reported that Benzyl adenine (BA) recorded LAI of 6.46 on variety Gudanie.

Table 4. Effect of plant growth regulators on marketable tuber yield of two potato varieties at different concentrations

Variety	Marketable Yield (ton/ha)		
	Gibberellic acid (GA_3)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	11.11^{de}	12.47^{de}	13.09^{cde}
Jalenie	8.21^{de}	7.41^{de}	4.44^{e}
	Benzyl aminopurine (BAP))		
	(DW) control	**0.1mM**	**0.2mM**
Belete	11.11^{de}	22.84^{abc}	16.23^{bcd}
Jalenie	8.21^{de}	11.85^{de}	13.09^{cde}
	Benzyl adenine (BA)		
	(DW) control	**0.1Mm**	**0.2mM**
Belete	11.11^{de}	26.62^{a}	23.95^{ab}
Jalenie	8.21^{de}	9.26^{de}	7.16^{de}
LSD (5%)		**10.05**	
CV (%)		**44.60**	

Means followed by the same letter(s) within columns and rows are not significantly different at 5% level of probability.

Analysis of variance showed marketable tuber yield was significantly ($P<0.05$) affected by plant growth regulators and variety and its interactions. The three PGRs increased marketable tuber yield on both varieties; although the increment due to BA was the highest (58.25%) followed by BAP (51.3%) and GA_3 (12.2%) at the lowest concentration (0.1mM) over the untreated control (DW) on variety Belete. However, the difference between the effect of BA and BAP was not significant (Table 4). Nevertheless, the increment owing to any of the three PGRs used on variety Jalenie was insignificant as compared to the effect on variety Belete although Belete is a high yielder variety as compared to Jalenie regardless of the effects of the PGRs used.

These findings were in agreement with the findings of Caldiz (1996) that foliar applications of BA or GA_3 or BA + GA_3 under both glasshouse and field conditions increased both tuber number and tuber yields although our work was on tuber treatment. This finding also affirmed that; BAP significantly increased tuber yields of both varieties. Previous study on a different variety (Gudanie) showed that when seed tubers were treated with BA with 0.1 mM, 0.2 mM and 0.3 mM, the yield increment over the untreated control (DW) was 19.82%, 17.21% and 14.9%, respectively (Kedir, 2016). Among the PGRs that have been used to study tuberization phenomenon in potato, GA_3 has been reported to have a consistent delaying or inhibiting effect on potato tuberization (Koda and Okazawa, 1983; Abdala *et al*. 1995) and this would have little effect on yield increment as obtained in the present study.

Likewise, treating potato tubers with plant growth regulators (BAP and BA) was highly significantly ($P<0.05$) affected the total tuber yield (Table 5). Analysis of variances showed that BAP and BA increased the total tuber yield of both potato varieties compared to GA_3 and control (DW). BAP and BA at the lowest concentration (0.1mM) increased the total tuber yield by 61.98% and 65.81% over the control respectively.

Table 5. Effect of plant growth regulators on total marketable tuber yield of two potato varieties at different concentrations

	Total Marketable Yield (ton/ha)		
Variety	**Gibberellic acid (GA_3)**		
	(DW) control	**0.1mM**	**0.2mM**
Belete	15.43^{cde}	17.32^{bde}	18.02^{bcd}
Jalenie	11.73^{de}	10.25^{de}	7.90^{e}
	Benzyl aminopurine (BAP)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	15.43^{cde}	25.86^{ab}	22.28^{abc}
Jalenie	11.73^{de}	15.31^{cde}	16.05^{cde}
	Benzyl adenine (BA)		
	(DW) control	**0.1mM**	**0.2mM**
Belete	15.43^{cde}	29.70^{a}	27.72^{a}
Jalenie	11.73^{de}	11.48^{de}	9.63^{de}
LSD (5%)		**9.63**	
CV (%)		**33.70**	

Means followed by the same letter(s) within columns and rows are not significantly different at 5% level of probability.

According to Ewing and Struik (1992) and Pavlista and Gall (2010), using exogenous cytokinins (BA and BAP), the number of tubers has been increased which led to increased total tuber yield. The application of plant growth regulators for tuberization, is a componential process in which according to Rodrýguez-Falcon *et al*. (2006), cytokinins (BA and BAP) may function to control tuber enlargement and growth which definitely has effect on total tuber yield. Because of cytokinin interfere with cell division, differentiation and induction production of potato was increased (Kefi *et al*., 2000). Unlike the cytokinins (BA and BAP), GA_3 inhibits the growth of tuber formation (Hannapel *et al*., 1985). Like the marketable tuber yield as discussed above, significant effects on the total tuber yield between the two cytokinins (BAP and BA) were not obtained on both varieties although Belete is naturally better variety in terms of tuber yield than Jalenie in spite of the PGRs effects. Similar researches by Kedir (2016) demonstrated that tubers pretreated with GA_3 and BA both at low concentration (0.1 mM), BA alone and GA_3 with 0.1 mM combined with BA with 0.1 mM significantly increased the total tuber yield by 24.64%, 19.71% and 19.52%, respectively over the untreated control on variety Gudanie. Ewing and Struik (1992) reported that using exogenous cytokinin, the number of tubers has been increased. One of these growth regulators is Thidiazuron that acts the same as cytokinins and has cytokinin like effects (Pavlista and Gall, 2010). The application of plant growth regulators for tuberization, is a componential process. Thus, there are several methods that produce a balance in PGRs for inducing tuberization (Tovar *et al*., 1985). Rodrýguez-Falcon *et al*. (2006) suggest that cytokinins may function to control tuber enlargement and growth.

CONCLUSION AND RECOMMENDATION

In addition to breaking seed tuber dormancy the use of plant growth regulators was not known to affect tuber yield and yield components of potatoes in Ethiopia. The present study was done at Kulumsa Agricultural Research Centre (KARC), Southeastern Ethiopia during the main cropping season of 2018 to determine the effect of three plant growth regulators (GA_3, BAP and BA) on yield and yield components of two majorly grown potato varieties (Belete and Jalenie). The experiment was laid out in a 2x3x3 factorial experiment composed of treatments of two varieties (Belete and Jalenie), three types of plant hormones viz. GA_3, BAP and BA each at two concentrations (0.1, 0.2 mM) and distilled water (DW) as untreated control. The results confirmed that BAP and BA significantly affected the tuber yield and yield components on both varieties including tuber weight, leaf area index, marketable and total tuber yield as compared to the effect of GA_3 and the untreated control (DW). BA at low concentration (0.1mM) increased the average tuber weight by 62.8%; while BAP by 59.17% over the control (DW) at 0.2mM. Similarly, leaf area index, marketable tuber yield and total tuber yield was increased significantly by BA and BAP over the control at the lowest concentration (0.1mM). However, the effect of the two PRGs (BA and BAP) was not significantly different on the aforementioned parameters. Besides, variety Belete was found to be better in terms of leaf area index, average tuber weight, marketable and total tuber yield regardless of PGRs. With the current findings, BA or BAP or both at the lowest concentration (0.1mM) could be used to pre-treat seed tubers to obtain better tuber yield and yield components from potato variety Belete and Jalenie in the Southeast Ethiopia.

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