Open Agriculture. 2017; 2: 220–229

DE GRUYTER OPEN

Research Article

Open Access

Gemeda Mustefa, Wassu Mohammed, Nigussie Dechassa, and Dandena Gelmesa*

Effects of different dormancy-breaking and storage methods on seed tuber sprouting and subsequent yield of two potato (*Solanum tuberosum* L.) varieties

DOI 10.1515/opag-2017-0023

Received November 12, 2016; accepted March 30, 2017

Abstract: Potato is an important food and cash crop which in Ethiopia is produced two or more times in a year. However, its productivity is low owing to a number of constraints including a) limited availability of quality planting materials, and b) poor tuber sprouting due to long dormancy period of improved varieties at the time of planting. Two consecutive experiments were conducted from November 2013 to June 2014: 1) to assess the effects of gibberellic acid (GA_3) and storage methods on seed tuber dormancy breakage of two potato varieties; and 2) to assess the effects of dormancy breakage treatments and storage methods on subsequent growth, yield and related traits of potato crop. The treatments in the first experiment consisted of two potato varieties (Bubu and Bate), three levels of GA_3 [0, 10 and 20 parts per million (ppm)], and three storage methods [in diffused light store (DLS), in pit store (PS), and in farm-yard manure (FYM)]. The first trial was laid out as a complete randomized design with four replications and conducted at Haramaya University, Ethiopia. The second trial consisted of seed from each treatment in the first experiment, planted in randomized complete block design with three replications on a farmers' field. The results showed that varieties, application of GA_3 and storage methods as well as the interaction among the variety and treatments significantly affected tuber dormancy period, sprouting characteristics and subsequent tuber yield. When tubers were treated with 20 ppm GA_3 and stored under FYM, the dormancy period was reduced from 102.5 and 52 to 36.5 and 31 days in improved and farmer's variety, respectively. Tuber treatment with 20 ppm GA_3 and stored under DLS, PS, and FYM, increased marketable tuber yield by 31.6%, 29.6%, and 33.6%, respectively for Bubu variety and by 92.5%, 78.4%, and 80.9% for Bate variety, respectively compared to non-GA_3 treated tubers stored under DLS, PS, and FYM. However, tubers of improved variety Bubu treated with 20 ppm GA_3 and stored under DLS produced the highest marketable tuber yield of 34.20 ton per ha. Tuber quality attributes (specific gravity, dry matter, and total starch content) were affected only due to interaction effects of variety and GA_3 application with the highest values at 20 ppm GA_3 for improved potato variety Bubu. In general, the research indicated that treating seed tubers with GA_3 and storing under DLS, PS or FYM promoted early tuber sprouting and better tuber yield of both varieties. These results suggest that, use of GA_3 treatment combined with different storage methods enhances early tuber sprouting and increases tuber yield. Nevertheless, further research should be continued to evaluate different potato varieties, GA_3 treatment, and storage methods under different atmospheric conditions and production seasons.

Keywords: dormancy breaking, gibberellic acid, potato, tuber yield

***Corresponding author: Dandena Gelmesa,** Haramaya University, College of Agricultural and Environmental Sciences, School of Plant Sciences, P.O. Box 138, Dire Dawa, Ethiopia, E-mail:dandenagalmesa@gmail.com

Gemeda Mustefa, Wassu Mohammed, Nigussie Dechassa, Haramaya University, College of Agricultural and Environmental Sciences, School of Plant Sciences, P.O. Box 138, Dire Dawa, Ethiopia

1 Introduction

Potato is regarded as a high-potential food security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (Adane et al. 2010). In areas with a tradition of more than one production cycle per year and a bimodal rainfall pattern, there is little time between growing seasons to permit adequate tuber sprouting of improved potato varieties released in Ethiopia. In general, there is a limited supply of high-quality seed tubers and it is one of the major constraints to potato production in many developing countries including Ethiopia (Gildemacher et al. 2009). In eastern Ethiopia in particular and in the country in general, potato area coverage and production cycle is increasing owing to increased use of irrigation facilities and economic importance of the crop. However, the Ethiopia potato breeding program has so far failed to develop varieties with a shortest enough dormancy period, which can fit the production cycle of most farmers. Most potato varieties released by research institutions in Ethiopia have suffered low rates of adoption by farmers, especially for irrigated agriculture and low moisture stress areas, due to long dormancy periods and other tuber quality attributes. Medium to long dormancy genotypes are thus not easy to incorporate into the predominant cropping system in which farmers retain seed from the previous harvest for replanting the next season (Abebe 2010). Surprisingly, local potato varieties which satisfy local demand for year-round production with good agronomic importance (e.g. short dormancy period, compact tuber setting, early maturing) have not been intensively studied for research and development work. For instance, potato genotypes with very short tuber dormancy are not looked at favorably by potato breeders, but a short dormancy is highly appreciated by smallholders in East Africa (Wachira et al. 2010) as it greatly facilitates the use of seed potatoes from their own harvest for subsequent planting of two to three times a year.

Furthermore, farmers generally use poor tuber sprouting techniques, which also contribute to poor supply of quality seed for year-round potato production (Abebe 2010; Nigussie 2011). Hence, this research aimed to study dormancy breaking methods using two potato varieties having contrasting dormancy periods, three concentrations of GA_3 under three storage methods (diffused light store (DLS), heap of farm-yard manure (FYM) store and pit store (PS) and to evaluate the effects on subsequent tuber growth and yield under field conditions.

2 Materials and methods

2.1 Description of the study sites

The tuber dormancy breaking experiment was conducted at Haramaya University and the field experiment was conducted at Rare Hora seed producer cooperative with in Haramaya district, Ethiopia. The area for the field trial is located at 9°29' N latitude, 42°7' E longitude at an altitude of 2022 meters above sea level. The mean annual rainfall is 700 mm and the average annual maximum and minimum temperature of 25.4°C and 8.6°C, respectively with mean relative humidity of 50%, ranging from 25 to 85%.

2.2 Description of experimental materials

Two potato varieties, Bubu and Bate, were used for the experiments. Bubu was released in 2011 by Haramaya University, having a yield potential of 39.5 ton per hectare (ha), an average dormancy period of three months, late blight resistance, matures in 99 days and has 27.49% dry matter content and 1.09 specific gravity (Habtamu et al. 2016; Tekalign 2011). Bate is farmers' variety having yield potential of 35 to 39 ton per ha under irrigation in the absence of late blight to which it is susceptible, has an average dormancy period of 51 days, has 23.7% dry matter content and 1.07 specific gravity (Habtamu et al. 2016; Helen et al. 2014).

For dormancy breaking and field evaluation experiments, a factorial arrangement of two potato varieties, three storage methods, and three GA_3 concentrations (0, 10 and 20 ppm) were combined. The dormancy breaking experiment was laid out in a completely randomized design with four replications while the field evaluation experiment was laid out in a randomized complete block design with three replications.

2.3 Experimental Procedures

Medium size seed tubers were selected, washed with distilled water, grouped into four replicates, each having equal tuber numbers, and treated with GA_3 solutions at three concentrations (0, 10 and 20 ppm) for 20 minutes in distilled water. From each GA_3 treatment, 30 seed tubers in four replicates were weighed and put in nylon woven bags with 0.5 x 0.4 mm mesh size and stored on DLS bed, in FYM, or PS for dormancy breaking experiment. Similarly, 90 seed tubers in three replicates were put in nylon woven bags with 0.5 x 0.4 mm mesh size and stored on DLS bed, FYM and PS for the field experiment. Seed tubers that were used for dormancy breaking and the field experiment were kept randomly in the same DLS, FYM, and PS. For this purpose a total of six pits, each 1x1x1 cubic meter area were dug, layered with maize straw upon which were placed the tubers before they were covered with soil to a depth of 30 cm. Similarly, other tubers were placed in 1 x 1 x 0.5 cubic meter pits and covered with 50 cm FYM.

For field experiment, the seed tubers treated with different concentration of GA_3 and stored in DLS, FYM and PS were planted at a spacing of 75 x 30 cm having 72 plants per plot (16.2 m^2 area). All cultural practices such as cultivation, pest and disease control, fertilization, weeding, and irrigation were done according to the local recommendation.

2.4 Data collection

2.4.1 Dormancy-breaking and tuber sprouting characteristics

Dormancy period was counted as the number of days from dehaulming (haulm cutting) to sprouting of 80% of the tubers with at least one sprout longer than 2 mm. Sprouting (%) was calculated as the percentage of the number of tubers in the sample. Sprout thickness (mm) and sprout vigor were measured for the sample tubers used to determine dormancy period. The average thickness of the apical sprout and one of or two lateral axillary sprouts were measured from the thickness of the longest ones to calculate sprout thickness per tuber. Sprout vigor score was evaluated based on the thickness of the base of the sprout and sprout length. The vigor score was based on a 5-point scale, where 1 = very low vigor (where more than half of the tubers in a sample had sprouts of < 1 mm thick and a length of < 3 mm), 2 = low vigor (where more than half of the tubers in a sample had sprouts of < 2 mm thick and a length of < 4 mm), 3 = good vigor (where more than half of the tubers in a sample had sprouts of < 4 mm thick and a length of < 4 mm), 4 = high vigor (where more than half of the tubers in a sample had sprouts of < 4 mm thick and a length of > 4 mm but were not firm and had not acquired the green colorations) and 5 = very high vigor as described for score 4 but having acquired the green coloration, and were sprouts were firm and had no visible defects (Shibario et al. 2006).

2.5 Growth, yield, and yield related parameters

Days to maturity were recorded when 50% of the plants were ready for harvest as indicated by the senescence of the haulms. The days were counted from emergence to maturity of the crop. Leaf area index (LAI) was estimated from growth and phenology of the field experiment. To determine LAI, five plants (hills) from each plot were randomly taken and tagged. Individual leaf area of the potato plants was estimated from leaf length using the formula developed by Firman and Allen (1989) and LAI was determined by dividing the total leaf area of a plant by the ground area covered by a plant using the formula:

Log 10 (leaf area in cm^2) = 2.06 x log10 (leaf length in cm)-)-0.458

Yield data were collected on average tuber number (ATN) per hill, average tuber weight (ATW) and marketable tuber yield. Average tuber number was calculated from tuber number per plant from five randomly selected plants (hills) at harvest. Average tuber weight (gram/tuber) was determined by dividing the total fresh tuber yield of each plot to the respective total tuber number per plot. Marketable tuber yield (ton per ha) was determined from the weight of tubers obtained from the net plot after sorting tubers which were free from diseases, insect pests and were greater than or equal to 20 gram.

2.6 Tuber quality parameters

Specific gravity of tubers (gram cm^{-3}) was determined by the weight in air and weight in water method. Five-kilogram tubers of all shapes, sizes, and weight were randomly taken from each plot. The selected tubers were washed with tap water. The samples were first weighed in air and then re-weighed suspended in water. Specific gravity was calculated using the following formula (Kleinkopf et al. 1987).

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air - Weight in water}}$$

Tuber dry matter content (%) was determined from five fresh tubers randomly taken from each plot and weighed at harvest. Then tubers were sliced and air dried for seven days and then in an oven at 65°C for 24 hours until a constant weight is attained. The dry weight was recorded and the dry matter percent calculated according to Williams (1968).

Total starch content (gram/100 g) was calculated from the specific gravity as follows:

Total starch (%) = 17.546 + 199.07 × (specific gravity-1.0988) (Yildrim and Tokuşoğlu 2005), where specific gravity was determined as indicated above by the weight in air and weight in water method.

2.7 Data 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% probability level was used to separate means when the analysis of variance indicated the presence of significant differences due to the main and interaction effects of variety, GA_3 and storage methods.

3 Results

3.1 Dormancy-breaking and tuber sprouting characteristics

Dormancy period and tuber sprouting (%) were significantly ($P < 0.05$) affected by interaction effects of variety, GA_3 application and storage methods (Table 1). Farmers' variety Bate had the shortest dormancy period of 31 days after 20 ppm GA_3 treatment and storage both under PS and FYM. This had reduced dormancy by about 42.8% as compared to GA_3 untreated tubers stored under DLS. The dormancy period for Bubu tubers treated with 20 ppm GA_3 and stored under both PS and FYM were also significantly reduced by 63 and 66 days, respectively, as compared to GA_3 untreated tubers stored under DLS (Table 2).

Increasing dose of GA_3 generally increased sprouting in both varieties and with all storage methods (Table 2). Application of 20 ppm GA_3 caused significantly highest level of sprouting in both varieties and storage methods. The lowest sprouting was seen in Bate tubers without GA_3 treatment regardless of storage methods. Variety, GA_3 application, and storage methods showed significant ($p < 0.05$) interaction on tuber sprout vigor (Table 1). The highest sprout vigor (4.5) was obtained for tubers treated with 20 ppm GA_3 and stored in DLS. On the other hand, both varieties with 0 ppm GA_3 treatment stored under any storage methods exhibited lowest sprout vigor.

Furthermore, two-way interactions of variety and treatments (GA_3 application and storage methods) significantly (p <0 0.05) affected sprout number per tubers (Table 1) with the highest number of sprouts per tuber (6.57 and 6.32) being recorded for tubers treated with 20 ppm GA_3 and stored under FYM and PS, respectively (Figure 1). However, the lowest number of sprouts per tuber (3.43 and 3.57) was observed in non-GA_3 treated tubers stored in either DLS or PS, respectively.

Similar to other tuber sprouting attributes, sprout thickness was also affected by two-way interactions of all factors, except variety by storage methods (Table 1). Thickest sprouts of 3.55 mm were obtained from tubers treated with 20 ppm GA_3 and stored in DLS while the thinnest sprouts of 1.55 mm were obtained from non-GA_3 treated tubers stored under FYM (Table 3).

3.2 Growth, yield, and yield related parameters

Variety, application of GA_3 and storage methods had significant interaction effects on subsequent field growth (days to maturity and leaf area index) (Table 1). For instance, field evaluation indicated that time to 50% physiological maturity was reduced for both varieties with increasing concentration of GA_3 under all storage methods (Table 4). However, leaf area index (LAI) of both varieties was increased for tubers planted from GA_3 treatment

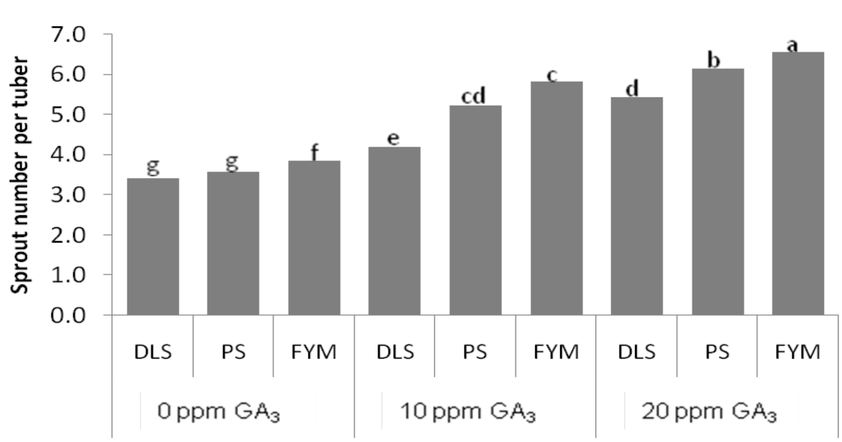

Figure 1: Effects of seed tuber treatment with GA_3 and storage methods on number of sprouts per tuber of two potato varieties grown in Ethiopia, Bars with the same letter(s) are not significantly different from each other at 0.05 probability level, DLS-Diffused light store, PS-Pit store, FYM-Farm-yard manure

Table 1: Mean squares value of dormancy period, tuber sprouting characteristics, growth and yield related traits of potato as affected by variety, GA_3, storage methods, and their interactions

SV	DF	DP	SP	SV	NSPT	ST	MD	LAI	ATN	ATW	MTY	SG	DMC	TSC
Variety (A)	1	6805.56**	1.39ns	13.48**	27.90**	3.71**	308.17**	0.14**	147.60**	175.40**	1606.10**	0.001**	9.88**	49.40**
GA_3 (B)	2	869.56**	479.78**	12.30**	36.06**	4.96**	355.85**	0.13**	11.01**	36.80**	400.70**	0.0005**	17.40**	24.60**
Storage (C)	2	6449.18**	36.58**	2.91**	6.76**	9.69**	38.35**	0.09**	1.68**	19.50**	0.60**	0.0000001ns	0.004ns	0.032ns
A x B	2	155.56**	1.84ns	0.39**	4.48**	0.25**	0.22ns	0.01**	0.30**	1.11*	14.40**	0.00001*	0.13**	0.64**
A x C	2	1678.43**	42.12**	0.43**	3.57**	0.05ns	3.39**	0.02**	0.01ns	0.37ns	0.02ns	0.000002ns	0.0002ns	0.04ns
B x C	4	197.89**	20.37**	0.07ns	0.76**	0.26**	8.41**	0.02**	0.02ns	1.19**	0.7**	0.0000003ns	0.001ns	0.01ns
A x B x C	4	21.81**	13.43*	0.21**	0.07	0.06ns	0.94*	0.002**	0.01ns	0.25ns	0.36**	0.000001ns	0.001ns	0.02ns
Error	51	2.44	2.67	0.03	0.04	0.03	0.31	0.0002	0.02	0.14	0.02	0.000003	0.003	0.04

SV-Source of variation, DF-Degree of freedom, DP-Dormancy period, SP- Sprouting percent, SV-Sprout vigor, NSPT-Number of sprout per tuber, ST-Sprout thickness, MD-Maturity days, LAI-Leaf area index, SN-Stem number per hill, ATN-Average tuber number per hill, ATW- Average tuber weight, MTY-Marketable tuber yield, SG-Specific gravity, DMC-dry matter content, TSC-Total starch content, ns-Non significant at 0.05 probability level

Table 2: Effects of variety, seed tubers treatment with GA_3 and storage methods on dormancy period, sprouting percentage, and sprout vigor of two potato varieties grown in Ethiopia

Character		Dormancy period (days)			Sprouting percentage			Sprout vigor (score)		
Variety	GA_3 (ppm)	DLS	PS	FYM	DLS	PS	FYM	DLS	PS	FYM
	0	102.50a	48.25e	46.75ef	91.67d	90.83d	92.50d	2.59gh	2.71g	2.03i
Bubu	10	83.00b	43.00g	41.00gh	99.17ab	95.84c	98.34ab	3.51c	3.24def	3.33cde
	20	70.50c	39.50h	36.50i	100a	99.17ab	100a	4.50a	3.92b	3.96b
	0	54.25d	35.00ij	33.25jk	91.67d	85.00e	95.84c	2.37h	1.75j	1.34k
Bate	10	46.00f	34.00jk	32.00kl	95.84c	97.50bc	99.17ab	3.05f	2.51gh	2.00i
	20	39.50h	31.00l	31.00l	100a	100a	100a	3.36cd	3.17ef	2.54gh
LSD (0.05)			2.22			2.32			0.25	
CV (%)			3.3			1.7			6.0	

Means in rows and columns in each character with similar letter(s) are not significantly different, DLS-Diffused light store, PS-Pit store, FYM-Farm-yard manure, LSD (0.05)-Least significant difference at 0.05 probability level, CV (%)-Coefficient of variation in percent

Table 3: Mean effects of seed tuber treatment with GA_3 and storage methods on sprout thickness (mm) of two potato varieties grown in Ethiopia

Treatment	Storage		
GA3 (ppm)	Diffused light store	Pit store	Farm-yard manure
0	2.40d	1.73g	1.55h
10	3.34b	2.21e	1.91f
20	3.55a	2.69c	2.13e
LSD (0.05)		0.17	
CV (%)		7.0	

Means in rows and columns in each interaction effect with similar letter(s) are not significantly different. LSD (0.05)-Least significant difference at 0.05 probability level, CV (%)-Coefficient of variation in percent

Table 4: Effects of variety, seed tuber treatment with GA_3, and storage methods on leaf area index and 50% physiological maturity of two potato varieties grown in Ethiopia

Character		Leaf area index			Days to maturity		
Variety	GA_3 (ppm)	DLS	PS	FYM	DLS	PS	FYM
	0	2.27f	2.23g	2.23g	96.00e	97.70d	97.70d
Bubu	10	2.50b	2.30ef	2.30ef	90.30j	94.30g	94.30g
	20	2.63a	2.36d	2.36d	85.70m	89.70l	90.00jk
	0	2.18h	2.18h	2.18h	103.00a	101.70b	101.70b
Bate	10	2.30e	2.21g	2.20gh	95.30f	99.00c	99.00c
	20	2.38c	2.30ef	2.30ef	91.00i	94.00h	94.00h
LSD (0.05)			0.03			0.92	
CV (%)			12.0			6.0	

Means in rows and columns in each character with similar letter(s) are not significantly different, DLS-Diffused light store, PS-Pit store, FYM-Farm-yard manure, LSD (0.05)-Least significant difference at 0.05 probability level, CV (%)-Coefficient of variation in percent

combined with DLS compared to PS and FYM. For instance, the highest LAI of 2.63 and 2.5 was recorded for Bubu variety treated with 20 and 10 ppm GA_3 and stored under DLS, respectively while the lowest LAI (2.18) was obtained from Bate variety without GA_3 under all storage methods (Table 4).

The interaction between variety by GA_3 was significantly ($p < 0.05$) affected ATN per hill (Table 1). The highest ATN (15) was recorded after 20 ppm GA_3 treatment and storage under DLS while the lowest ANT (12) was recorded from non-GA_3 treated tubers stored under PS and FYM (Table 5). On the other hand, the highest ATW of 62.5 and 61.2 gram was recorded from 20 ppm GA_3 treated tubers stored under DLS and PS while the lowest ATW (57.8 gram) was from non-GA_3 treated tubers stored both under PS and FYM (Table 5).

Interestingly, interaction effects of variety, GA_3 and storage methods significantly ($p < 0.05$) affected marketable tuber yield of both varieties (Table 1). The result indicated that increasing GA_3 concentration from 0 to 20 ppm significantly increased marketable tuber yield for both varieties in all storage methods at least by 50% as compared to non-GA_3 treated tubers stored under all storage methods (Table 6). However, at the same treatment combinations of GA_3 and storage methods, Bubu variety produced a greater marketable tuber yield (ton per ha) than Bate variety.

3.3 Tuber quality parameters

Specific gravity (SG), dry matter (DM) content and total starch content were significantly ($p < 0.05$) affected by interaction between variety and GA_3 only (Table 1). The highest SG, DM and total starch content were observed at 20 ppm GA_3 treated Bubu variety, whereas the lowest values for these parameters were obtained for non-GA_3 treated Bate variety (Table 7). However, the value of SG for Bubu variety treated with 10 and 20 ppm GA_3 was in statistical parity. The highest (17.7%) and lowest 13.3%) value of total starch content was observed at 20 ppm GA_3 treated Bubu variety and non-GA_3 treated Bate variety, respectively (Table 7).

Table 5: Effects of seed tuber treatment with GA_3 and storage methods on total tuber number per hill and average tuber weight of two potato varieties grown from treated seed tube in Ethiopia

Character	Average tuber number per hill			Average tuber weight (g/tuber)		
GA_3 (ppm)	DLS	PS	FYM	DLS	PS	FYM
0	12.80d	12.20de	12.20de	60.50bc	57.80d	57.80d
10	14.00b	13.10c	13.10c	61.10b	59.90c	59.60c
20	15.00a	13.90b	13.90b	62.50a	61.20b	60.90bc
LSD (0.05)		0.21			0.44	
CV(%)		13.0			6.0	

Means in rows and columns in each interaction effect in each character with similar letter(s) are not significantly different. DLS-Diffused light store, PS-Pit store, FYM-Farm-yard manure, LSD (5%)-List significant difference at 0.05 probability level, CV (%)-Coefficient of variation in percent

Table 6: Effects of variety, seed tuber treatment with GA_3 and storage methods on marketable tuber yield of two potato varieties grown in Ethiopia

Character		Marketable tuber yield (ton per ha)		
Variety	GA_3 (ppm)	DLS	PS	FYM
	0	25.98e	26.00e	26.20e
Bubu	10	30.50c	29.80d	29.80d
	20	34.20a	33.70b	33.60b
	0	12.90j	13.30i	13.10i
Bate	10	19.90h	20.50h	20.00h
	20	24.97f	23.73g	23.70g
LSD (0.05)			0.23	
CV (%)			6.0	

Means in rows and columns with similar letter(s) are not significantly different. DLS-Diffused light store, PS-Pit store, FYM-Farm-yard manure, LSD (0.05)-List significant difference at 0.05 probability level, CV (%)-Coefficient of variation in percent

Table 7: Effect of variety and GA_3 application on specific gravity, dry matter content, and total starch content of potato varieties grown in Ethiopia

Quality trait	Variety	GA_3 (ppm)			LSD (0.05)	CV (%)
		0	10	20		
Specific gravity	Bubu	1.090b	1.095a	1.099a	0.002	20.0
	Bate	1.077d	1.085c	1.090b		
Dry matter content (%)	Bubu	25.20e	26.28c	27.00a	0.10	20.0
	Bate	24.30f	25.30d	26.34b		
Total starch content	Bubu	15.60d	16.70b	17.70a	0.20	12.0
	Bate	13.30f	14.90e	15.90c		

Means in rows and columns in each parameter with similar letter(s) are not significantly different. LSD (0.05)-List significant difference at 0.05 probability level, CV (%)-Coefficient of variation in percent

4 Discussion

4.1 Dormancy-breaking and tuber sprouting characteristics

Application of different dormancy-breaking chemicals and storage methods have been proposed as one of the most effective methods to promote tuber sprouting and improve subsequent tuber yield and quality in the field (Suttle 1996; Shibairo et al. 2006; Abebe 2010). Diffused light store uses indirect natural light and good ventilation or airflow instead of low temperature to control excessive sprout growth, reduce storage loss of seed potatoes, increase sprout number per tubers and has been shown to increase yield due to improved seed vigor (Demo et al. 2004; CIP 1984). The previous research also showed that tuber treatment with GA_3 causes breakdown of starches and accumulation of renewable sugars in potato tubers that can stimulate germination and consequently dormancy-breaking (Alexopoulos et al. 2007; Hember 1985). Dogonadze et al. (2000) also observed that exogenous application of GA_3 promoted tuber sprouting by enhancing RNA and DNA synthesis. However, Demo et al. (2004) reported that DLS storage delays sprouting by more than four weeks in some genotypes. Similar to the previous findings, our study also confirmed that tubers treated with GA_3 and stored under DLS resulted in thick, deep green, and strong sprouts for both varieties compared to treated with GA_3 and stored under PS or FYM. Moreover, Struik et al. (2006) indicated that high concentration of GA_3 stimulated break down of starch to glucose due to stimulation of respiration caused by external gibberellins that in turn lead to faster sprouting and thick sprout. Formation of thicker sprouts can be induced when high concentrations of GA_3 were applied, especially with longer duration of exposure.

On the contrary, tubers treated with GA_3 and stored under PS or FYM resulted in faster sprouting, weak sprout vigor and thin sprout possibly due to heat build-up during storage (Bencini 1991) and low light penetration (Shibairo et al. 2006) compared to tubers stored in DLS. The high temperature causes an increase in growth rate while the low light intensities lead to etiolation. According to Menza et al. (2008) and Andre et al. (2007) tubers stored at high temperature under PS and FYM produce more sprouts per tubers. High relative humidity and increased CO_2 concentration are known to promote sprout growth in potato (Menza et al. 2008) for seed tubers stored in pits. Ayelew et al. (2014) reported that different traditional seed tuber storing techniques are used in Ethiopia including a warmer place in the house, in pits covered with soil and covering the tubers with crop residues or dry animal dung. These findings are extremely relevant in the importance of using PS and FYM as alternative to DLS in combination with GA_3 for resource-poor farmers trying to promote tuber sprouting. Our findings also suggest that the variety with low DM and SG tend to break dormancy faster than variety with high DM content and SG under all treatment combinations. Dry matter content and SG seems to be negatively correlated with tuber dormancy period in this study contradicting the findings of Beukema and van der Zaag (1990) who stated no correlation has been found between DM content and dormancy period. Rather, the authors suggests that length of dormancy depends on variety, tuber maturity, soil, and weather conditions during both growth and storage.

4.2 Growth, yield, and yield related parameters

It is worth noting that application of GA_3 in combination with storage methods (DLS, PS, and FYM) enhances termination of dormancy breakage and subsequent growth, tuber yield, and yield related attributes than non-GA_3 treatment under all storage methods. This may give an alternative to poor farmers who cannot afford DLS technologies to use cost effective and locally applicable storage methods in combination with GA_3 treatment. Similar to the current findings, Reeve et al. (1973) reported that tuber weight is affected by variety, storage methods, and environmental factors to enhance tuber growth. The authors further described that the growth of tuber tissue is the function of both cell division and expansion.

External GA_3 application and tuber storage conditions may also influence the number of tubers produced per hill. According to Bodlaender and Marinus (1984), tubers stored in traditional storage systems resulted in low total tuber number and yield due to high incidence of disease and tuber moth damage during storage as compared to DLS. However, this effect seems to be improved after traditional dormancy breaking methods combined with GA_3 application. In our study, for instance, neither disease nor potato tuber moth occurred on tubers stored under PS or FYM yet both storage methods resulted in significantly low yields. In agreement with the current findings, Allen et al. (1979) and Arsenault and Christie (2004) reported that post-harvest tuber storage condition in combination with GA_3 application on different potato varieties resulted in significant differences in average and total tuber numbers per plant produced among varieties. This is probably due to genetic and physiological aging difference between cultivars in response to exogenous GA_3 application and storage conditions according to these authors.

4.3 Tuber quality parameters

Different tuber dormancy breaking methods used in this study had no significant effect on SG, DM content or total starch content of either variety grown under field conditions. The only interaction effects were seen between variety and GA_3 treatment, affecting tuber attributes such SG and total starch content. Abebe (2010) reported that tuber treatment with GA_3 significantly increased specific gravity, dry matter and starch content of potato. Feltran et al. (2004) concluded that technological quality characteristics like starch content are influenced by genotype as well as exogenous application of plant growth regulators. Tuber treatment with GA_3 before planting improves subsequent field growth and nutritional values of potato (Feltran et al. 2004; Mikitizel 2004). A positive correlation between SG and starch content, as reported by Gould (1988) also justifies how tuber quality attributes might have a positive correlation between each other.

5 Conclusion

Medium-term to longer tuber dormancy periods of potato varieties released in Ethiopia is one of the main limiting factors for farmers of smallholdings to access good quality seed at the time of planting. Although, the experiment was conducted in one location and one season using only two varieties, it is reasonable to point out that the exogenous application of GA_3 at 20 ppm and combined with different storage methods immediately after harvest resulted in a shortened dormancy period, increased sprout mass and improvements in both yield and quality (SG, DM, and total starch content) of the subsequent potato generation. Exogenous application of GA_3 to tubers combined with locally applicable storage methods can possibly promote tuber sprouting. It is anticipated that these treatment combinations are more beneficial for the early breaking of dormancy in seed tubers for rapid planting of tubers after harvest. The response of potato varieties to combination of GA_3 and storage methods also differed due to genetic factors, GA_3 treatment, and storage methods in the current study. Results of our study for instance depicted that, there is a significant interaction between variety and treatments (GA_3 and storage methods) on dormancy period, sprouting (%), sprout vigor, tuber maturity date, LAI and marketable tuber yield, indicating the fact that, GA_3 and storage method recommended for one variety may not work for the other.

In general, treating tubers of an improved variety with GA_3 at 20 ppm before storage in DLS, PS, or FYM promoted early dormancy termination and early emergence of shoots of high marketable tuber yield production. The findings of this study are also of great importance in potato seed production for rapid seed multiplication as well as for a certification systems to speed up the process of virus testing. However, the experiment was conducted only for one season both for dormancy breaking and subsequent field evaluation using two potato varieties. Hence, it deserves further study to evaluate the effects of these treatments effects on early tuber dormancy age and subsequent tuber yield by including more potato varieties, GA_3 treatment, and storage methods under various weather conditions and storage conditions such as temperature and relative humidity.

References

Abebe C., Effect of Gibberellic acid on tuber dormancy breaking, subsequent growth, yield and quality of potato (*Solanum tuberosum* L.), M.Sc. Thesis Presented to the School of Graduate Studies of Haramaya University, Haramaya, Ethiopia, 2010

Adane H., Miranda P.M.M., Agajie Tesfaye, Willemien J.M.L., Alfons O.L., Admasu Tsegaye *et al.*, Analysis of seed potato systems in Ethiopia. Am. Potato Res. J., 2010, 87, 537-552

Alexopoulos A.A., Akoumianakis K.A., Vemmos S.N., Passam H.C., The effect of postharvest application of gibberellic acid and benzyl adenine on the duration of dormancy of potatoes produced by plants grown from TPS, Postharvest Bio. Tech., 2007, 46, 54-62

Allen E.J., Bean J.N., Griffith R.L., O‟Brien P.J., Effects of length of sprouting period on growth and yield of contrasting early potato cultivars, J. Agric. Sci. (Camb.), 1979, 92, 151-163

Andre C.M., Ghislain M., Bertin P., Qufir M., Herrera M.D.R., Hoffmann L., *et al.*, Andean potato cultivars (*Solanum tuberosum* L.) as a source of antioxidant and mineral micronutrients, Agri. Food Chem. J., 2007, 55, 366-378

Arsenault W.J., Christie B.R., Effect of whole seed tuber size and pre-plant storage conditions on yield and tuber size distribution of Russet Burbank, Am. J. Potato Res., 2004, 81, 371-376

Ayalew T., Struik P.C., Adane H., Characterization of seed potato (*Solanum tuberosum* L.) storage, pre-planting treatment and marketing system in Ethiopia: The case of West-Arsi Zone, Afr. J. Agri. Res., 2014, 9(15), 1218-1226

Bencini M.C., Potato (*Solanum tuberosum* L.). In: Walston (Ed.), Postharvest and processing technologies of African stable foods: A technical compendium J.P., 1991, 215-220

Beukema H.P., van der Zaag D.E., Introduction to potato production, Center for Agricultural Publishing and Documentation (Pudoc), Wageninge, 1990, 206p

Bodlaender K.B.A., Marinus J., Effect of physiological age on growth vigor of seed potatoes of two cultivars. 3. Effect on plant growth under controlled conditions, Potato Res., 1987, 30, 423-440

CIP (International Potato Center), Potato for the developing world. A collaborative experience. International Potato Center, Lima Peru., 1994, 150p

Demo P., Akoroda M.O., El-Bedewy R., Asiedu R., Monitoring storage loses of seed potato (*Solanum tuberosum* L.) tubers of different sizes under diffused light conditions. Proceedings, 6th triennial congress of the African Potato Association (APA), 5-10 April, 2004, Agadir Moroco, 2004, 363-370

Dogonadze M.Z.; Korableva N.P.; Platonova T.A., Shaposhnikov G.L., Effects of gibberellin and auxin on the synthesis of abscisic acid and ethylene in buds of dormant and sprouting potato tuber. Prikladnaia Biokhimiia i Mikrobiologiia, 2000, 36(5), 588-591

Feltran J.C., Lemos L.B., Vieites R.L., Technological quality and utilization of potato tubers, Sci. Agric., 2004, 61, 598-603

Firman D.M., Allen E.J., Estimating individual leaf area of potato from leaf length, Agri. Sci. J., 1989, 112, 425-426

Gildemacher P., Kaguongo W., Ortiz O., Tesfaye A., Gebremedhin W., Wagoire W.W., *et al*., Improving potato production in Kenya, Uganda and Ethiopia, Potato Res., 2009, (52), 173-205

Gould W.A., Specific gravity-its measurement and use. Chipping Potato Handbook, 1995, 18-21

Habtamu G., Wahassu M., Beneberu S., Evaluation of physico-chemical attributes of potato (*Solanum tuberosum* L.) varieties in eastern Ethiopia, Greener J. Plant Breeding Crop Sci., 2016, 4(2), 027-036

Helen T., Nigussie D., Tekaling T., Assessing the yield performance of improved and local potato (*Solanum tuberosum* L.) cultivars grown in Eastern Ethiopia, Adv. Life Sci. Tech., 2014, 24, 41-48

Hemberg T., Potato rest. In: PH Li, (ed.), Potato Physiology. Academic Press, Orlando, FL. 1985, 354-388

Kleinkopf G.E., Westermann D.T., Specific gravity of russet burbank potatoes, Am. Potato J., 1987, 64, 579-587

Menza M.K., Shibairo S.I., Nyankanha R.O., Demo P., Kabira J.N., Gildemacher P., Effects of pit, dark and cold pre-storage treatments and their duration on dormancy breaking and sprouting of seed potato tubers (*Solanum tuberosum* L.), Kenya Agricultural Research Institute, National Horticultural Research Center, Kenya, 2008, 12p

Mikitzel L.J., Influencing seed tuber yield of ranger russet and shepody potatoes with gibberellic acid. Am. J. Potato Res, 1993, 70, 667-676

Nigussie Dechessa, LSB matching potato research and extension to farmers demands, *In:* Local Seed Business Newsletter, Issue 5, 2011, www.portals.wi.wur.nl/files/docs/LSB%20Newsletter

Reeve R.M., Timm H., Weaver M.L., Parenchyma cell growth in potato tubers. I. Different tuber regions, Am. Potato J., 1973, 50, 50-58

Shibairo I.S., Demo P., Kabira J.N., Gildemacher P., Gachango E., Menza M., *et al*., Effects of gibberellic acid (GA_3) on sprouting and quality of potato seed tubers in diffused light and pit storage conditions, J. Biol. Sci., 2006, 6, 723-733

Struik P.C., Van der Putten P.E.L., Caldiz D.O., Scholte K., Response of stored potato seed tubers from contrasting cultivars to accumulated day-degrees, Crop Sci., 2006, 46, 10-17

Suttle J.C., Dormancy in tuberous organs: problems and perspectives. In: G.A. Lang (eds.). Plant Dormancy: Physiology, Biochemistry and Molecular Biology. CAB International, Wallingford, UK, 1996

Tekalign T., Registration of Bubu, a medium maturing improved potato (*Solanum tuberosum* L.) variety for the eastern highlands of Ethiopia, East Afr. J. Sci., 2011, 5(1), 69-71

Wachira G., Barker I., Schulte-Geldermann E., Effect of field multiplication generation on seed potato (*Solanum tuberosum* L.) quality in Kenya. In: Paper presented at the symposium of Potato Agro-physiology, European Association of Potato Research (EAPR). Nevsehir, Turkey. 20-24 September, 2010, 163-169

William M.A., Woodbury G.W., Specific gravity dry matter relationship and reducing sugar changes affected by potato variety, production area and storage. Am. Potato J., 1968, 45(4), 119-131

Yildrim Z. and Tokuşoğlu O., Some analytical quality characteristics of potato (*Solanum tuberosum* L.). Minitubers (cv.nif) developed via in-vitro cultivation, Electronic J. Envi. Agri. Food Chem. 2005, 1579-4377