

Effect of Tuber Size, Storage Time and Storage Environment on Dormancy and Sprouting Characteristics of Some Potato (Solanum Tuberosum L.) Cultivars

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Abstract
A study was conducted to investigate the influence of tuber size, storage time and storage environment on storage losses and seed tuber quality of three selected potato cultivars under diffused light storage (DLS) structures in three locations in 2012/2013 in the Tigray region, North Ethiopia. The treatments consisted of two environments (locations), three potato cultivars (Gera, Gudene and Jalene) and four tuber size categories [very small (20-30mm), small (31-40mm), medium (41-50mm), and large (51-65mm)] arranged in Randomized Complete Block Design with three replications. Data pertaining to sprouting characteristics were recorded for 28 weeks at monthly interval. The larger tubers had better sprouting ability than the rest of the tuber sizes. Gudene and Jalene cultivars recorded more number of sprouts per tuber at F.weyni storage environment. In contrast Gera cultivar recorded few numbers of sprouts until week 28. So, de-sprouting treatment is recommended for Gera cultivar. Number of sprouts per tuber, length and thickness of sprouts increased with increasing storage time. At F.weyni storage environment, large tuber size categories of all three potato cultivars had more number of sprouts per tuber than in the other storage environments. Generally, storing medium (41-50mm) and large (51-65mm) tuber size categories of potato tubers is recommended for a sustainable quality seed supply; Potato tubers should be stored at warm storage environments when short term storage is desired; however they should be stored at cool environments for long term storage.
Keywords: dormancy, sprouting, potato, tuber size, cultivar, diffused light storage

1. Introduction

Potato (*Solanum tuberosum* L.) popularly known as 'The King of Vegetables' is a perennial crop belonging to the family Solanaceae. It is the third most important food crop in the world in production volume after rice and wheat (CIP, 2011). The diverse agro-ecology in Ethiopia also allows a year round potato production. However there is no local private or public commercial seed producer and the informal seed potato system covers 98.7% of the seed tubers required for planting (Endale *et al*., 2008a). In the informal seed potato system, seed tuber is produced and distributed by the farmers themselves without any technical support from other organizations and breeding centres (Adane *et al*., 2010). Sprouting characteristics of potato tubers is greatly influenced by the storage environment, cultivar and tuber size. According to (Abeygunawardena *et al*., 1964), since different storage areas experience different temperature and relative humidity conditions, it has a great role in the quality of the stored potato tubers. In order to solve the ever increasing seed potato demand in the country, the seed potato sector should be supported through an intensive research. So the present study was conducted to study the influence of tuber size, cultivar and storage environment on storage quality of some selected potato cultivars so as to contribute some for the ever increasing seed tuber demand in the region and as a whole in the country and to help the countries horticultural development policy. And the objectives of the current study are to determine the effect of storage environment and tuber size on storage and seed tuber quality of each cultivar; and to investigate the influence of time of storage on the sprouting seed tuber quality of selected potato cultivars.

2. Materials and methods

The experiment was conducted from September 2012 to March 2013 under diffused light storage (DLS) structures at Elala and F.weyni in the Tigray Region, Northern Ethiopia. The two environments, Elala (5 km north of Mekelle in Enderta Wereda) and Felegeweyni (F.weyni) (5 km north of Atsbi in Atsbi-wemberta Wereda), differ in altitude, mean monthly minimum and maximum temperature and other weather conditions (Table 1) and are the major potato growing areas in the region. Detailed description and geographical environment of the experimental areas is shown in Table 1.

Table 1: Geographical environment, altitude and mean monthly temperature of the study sites

Study Site	Wereda*[1]	Latitude	Longitude	Altitude (m.a.s.l.)	Av Min Temp (^{O}C)	Av Max Temp (^{O}C)
Elala	Enderta	13.518° N	39.501° E	1970	12.0	27.1
Felegeweyni	Atsbi- wemberta	13.909° N	39.796° E	2622	9.4	19.8

1. Wereda = administrative structure below zone region in Ethiopia; m.a.s.l. = meters above sea level; Av Min Temp=Average Minimum Temperature; Av Max Temp=Average Maximum Temperature.
N.B. Source of weather data (Temperature) is the Ethiopian Meteorology Agency, Mekelle branch.

Twelve treatment combinations consisting of three well adapted and good performing potato cultivars (Jalene, Gera and Gudene) and four tuber sizes categories [very small (20-30mm), small (31- 40mm), medium (41-50mm) and large (51-65mm)] were laid out in Randomized Complete Block Design (RCBD) with three replications. Tubers for the different treatments were stored in diffused light storage (DLS) houses. The DLS at each environment was partitioned into three sections, i.e. each layer of the shelves was considered as blocks and each block was further sub-divided into 12 compartments (plots). Spacing was 60cm and 25cm between the blocks and the plot respectively. Size of the compartments (plots) was 50cm*50cm (2500cm^2). Manual Calliper was used to measure tuber diameter. Each DLS was partitioned in to three shelves. Each shelf was considered as a block and each shelf (block) was sub-divided into twelve compartments (experimental units). Each of the 4Kg tubers weighed using the sensitive balance from each potato cultivar and each tuber size levels and was placed in a meshed plastic container. Broad spectrum insecticide Diazinon was sprayed to the tubers In order to disinfect the storage area.

Temperature and relative humidity data was recorded using a data logger (HOBO U10-003) which was installed at each storage structures; and HOBO ware software (version 3.2.1, 2011) was used for the logger operation (Figures 1).

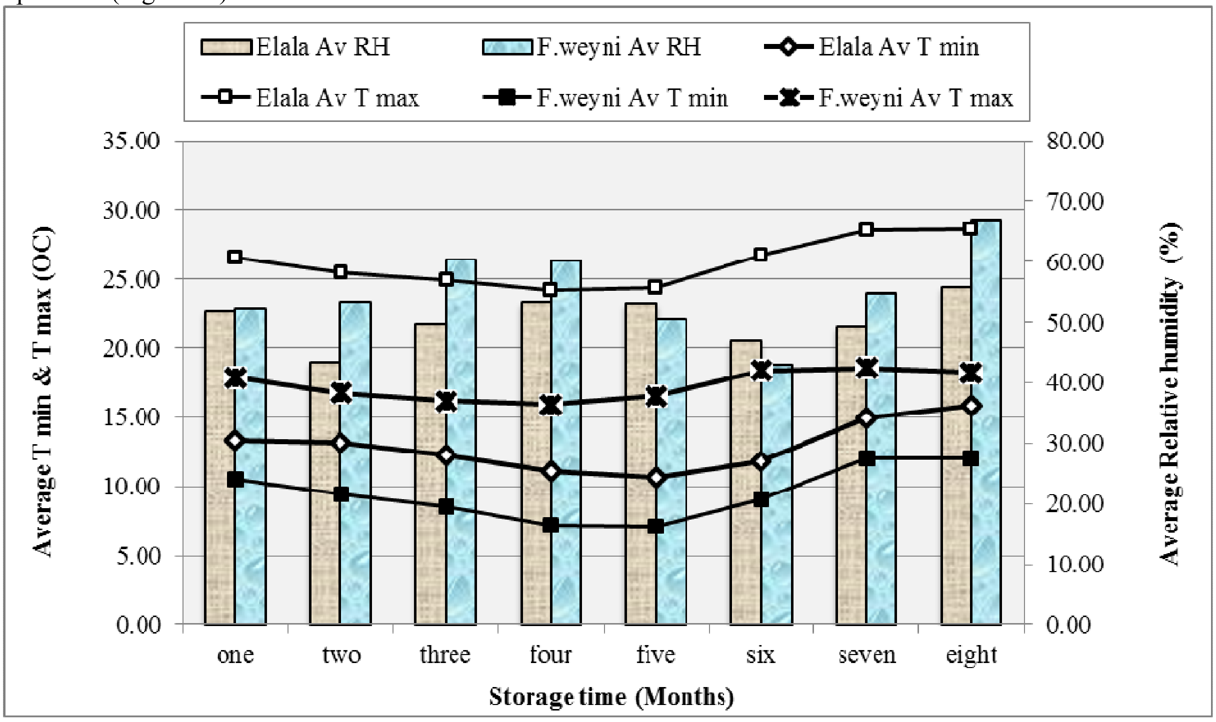


Figure 1: Average maximum and minimum temperatures; and relative humidity from the data logger inside the DLS at Elala and F.weyni storage sites during the entire storage period.

As for data on sprouting (number of sprouts per tuber, longest sprout length/thickness at time of each assessment, lateral sprout length/thickness), 10 randomly selected tubers were marked (with a permanent marker) from each plot and repeated measurements on sprouting characteristics (number of sprouts per tuber, sprout length and thickness of sprouts) were taken from the same samples up to the end of the experiment.

First data were checked for meeting all ANOVA assumptions and then data were subjected to general linear model (GLM) statistical analysis of variance (ANOVA) as suggested by (Gomez and Gomez, 1984). Then the data was analyzed using statistical software program (Gen-stat 16th edition). Mean separation were made where the treatments differed significantly. Whenever the treatment was significant, least significance differences (LSD) by Tukey's multiple range comparison was used for mean separation at p=0.05 &p=0.001. Correlations analysis was also done in order to know the relationship among the response parameters.

3. Results and Discussion

3.1. Length of dormancy period

There was a highly significant ($P<0.01$) interaction effect among cultivar and tuber size; however there was no significant difference for the interaction of cultivar and storage environment in respect of length of the dormancy period and days to full sprouting. From Table 2, it could be seen that for all potato cultivars, the number of days for dormancy break increased with decreasing tuber size which implies that the bigger tubers break their dormancy earlier than the smaller ones. Moreover for all tuber size levels, cultivar Jalene ended its dormancy period earlier than the other cultivars. At F.weyni, all potato cultivars and tuber size levels had longer dormancy period than the other storage site. The relatively cool climate at F.weyni (Appendix Table 9 and Appendix Figure 1) initiated the potato tubers to stay dormant where as the relatively higher temperature at and Elala might have shortened the dormancy period. Struik (2006) reported that environmental factors such as relative humidity, temperature, photo period and diffuse light during storage affect physiological age; specially the temperature effect is highly complex and cultivar specific. Carli *et al*. (2012) also found similar result where they found that under cellar storage the dormancy period ranged from 77 to 115 days; however it took 99 to 174 days under the cold storage conditions. Moreover, the present result is in line with the finding of Bornman and Hammes (1977) where they conducted an experiment with four potato varieties and different storage temperatures. They reported that at 11-12^{o}C, the average dormancy period was 86 days; however, it increased by 27 and 54 days when temperature was lowered by 4^{o}C and 8^{o}C respectively.

Length of dormancy period ranged between 45.67 and 109.83 days (Table 2). Very small sized tubers of cultivar Gera required significantly the maximum number of days (109.83 days) for dormancy break. On the other hand, significantly short time (45.67 days) was taken by large sized tubers of cultivar Jalene. Overall, there was a difference of 64.16 days between the fastest and slowest dormancy period depicting that potato tuber of different cultivars and sizes can manifest a wide variation for ending their dormancy period. When small and large seed tubers are stored in the same environment, the smaller seed tubers have a longer dormancy period and therefore will sprout later than larger sprouts (Struik and Wiersema, 1999). The present result agrees with the findings of Endale *et al*. (2008a) where they studied the performance of some potato varieties for dormancy break and sprout growth after storing the seed tuber for 216 days in DLS and observed that the varieties differed in their length of dormancy i.e. variety AL-624 had 14 days dormancy period, whereas tubers of the variety Genet took 52 days to break dormancy.

Attempt was made to perform correlation analysis among all parameters. There was highly positive correlation (0.87^{**}) between days to dormancy period and days to full sprouting implying those tubers which break their dormancy will be ready for planting earlier than the others. However, these two parameters (days to dormancy period and days to full sprouting) were negatively correlated with all the other sprouting characteristics (Table 4). This implies that, those tubers with shorter dormancy period exhibited superior sprouting characteristic.

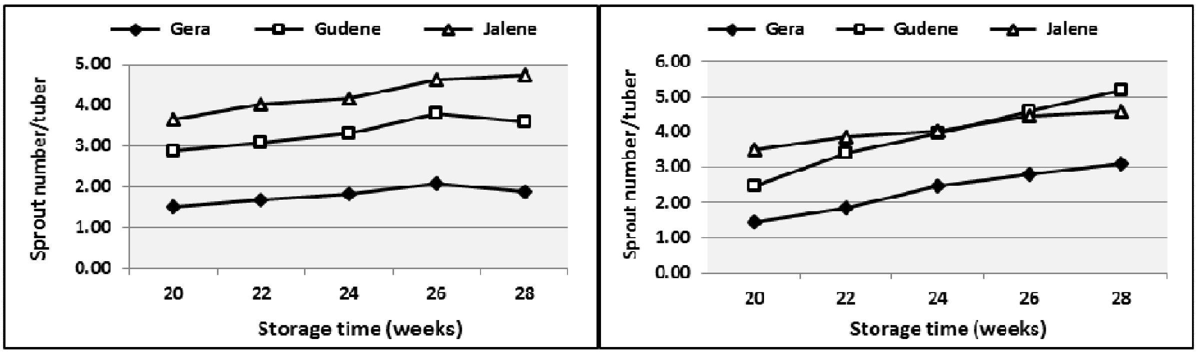
3.2. Number of sprouts per tuber

The interaction effect of potato cultivar and tuber size revealed significant difference for the number of sprouts per tuber at week-28 (Table 2). Number of sprouts per tuber increased progressively with increase in tuber size for all cultivars (Gera 3 is the only exception). The duration of apical dominance as well as the number of sprouts per tuber is a varietal characteristic (Van Es and Hartmans, 1987). Planting a tuber with very few number of sprouts may cause the production of very big tubers but reduced yield (Sterrett, 2009). There was also clear difference among the cultivars in terms of the number of sprouts; i.e. Gera cultivar had the lowest number of sprouts per tuber of the three potato cultivars for all tuber size levels. Potato cultivars behave differently in terms of their sprouting characteristics during storage time. According to Van Es and Hartmans (1987), sprouting behaviour and the number of sprouts per tuber are varietal characteristics. Diop (1998) also reported that, the total skin thickness can vary substantially depending on variety and growing conditions. Maximum number of sprouts was recorded from large tubers of the cultivar Jalene (6.78) followed by large tubers of Gudene (6.30). On the other hand, lowest number of sprouts was recorded from the very small and medium tubers of the Gera cultivar (2.13 and 2.47 respectively). The present result is in agreement with the findings of Wiersema (1989) who studied how tuber size affects sprout number. The author used seed size groups (1-5, 5-10, 10-20 and 40-60 Grams) and found that as the size of seed tuber increases, the number of sprouts increases. Larger seed pieces are likely to have multiple eyes, resulting in an increased number of stems per hill and until the sprouts generate a new root system, these sprouts are dependent upon the nutrients and energy stored in the seed piece (Sterrett, 2009). While studying the dormancy duration and sprouting characteristics of different sized micro tubers, Sharma *et al*. (2012) found that the rate of sprouting and number of sprouts per micro tuber showed a gradual increase with the increasing size of micro tubers; there was also a gradual increase in dormancy duration with decreasing size of micro tubers.

The interaction effect of potato cultivar and storage environment also revealed significant difference for the number of sprouts per tuber at week-28. Highest number of sprouts per tuber was recorded from Gudene cultivar stored at F.weyni (5.18). However, the lowest (1.88) was recorded from Gera cultivar at Elala (Table 3). Gudene and Gera cultivars had more number of sprouts at F.weyni storage environment, where as Jalene scored more number of sprouts at Elala.

At the end of the storage period, all tuber size categories of the cultivar Gera had less than three sprouts per tuber (Table 2). This is most probably due to the presence of high apical dominance characteristics in the tubers which might be unique to the particular cultivar. Carli *et al*., (2012) stated that a tuber with an average number of less than three sprouts per tuber is considered as partial apical dominance behaviour. Apical dominance is a physiological phenomenon characterized by exhibition of dominant bud over the others by suppressing the sprouting of other buds whereas multiple sprouting is characterized by appearance of several buds sprouting along the tuber (Carli *et al*., 2012). The disadvantage of apical dominance is that it has few main stems that result in the formation of a smaller number of tubers which may grow too large for proper market size **(**Pinhero *et al*., 2009**).** So it is possible to arrive at the conclusion that the tubers of Gera cultivar had partial apical dominance behaviour even after 28 weeks of storage period. Sterrett (2009) and Carli *et al*. (2012) also stated that reduced stem number is often associated with a small tuber set and a large tuber size. Moreover, Goodwin *et al*. (1969) also stated that since it has a strong correlation with the number of main stems present in the field, the number of sprouts in a tuber at plantinting is a very important factor in potato cultivation. So based on these justifications, the cultivar Gera does not fit the minimum requirements for planting even at the 28th week of storage period.

In F.weyni storage environments for all cultivars, number of sprouts per tuber increased consistently throughout the whole storage time from week 20 to week 28 (Fig. 2, B). Number of sprouts per tuber also increased consistently at Elala storage environment from week 20 to week 26 (Fig. 2, A).



A B

Figure 2: Sprout number/tuber from week 20 to week 28; where: (A) Elala storage environment; and (B) F.weyni storage environment

Table 2: Interaction effect of cultivar and tuber size on dormancy break, sprout number per tuber, longest sprout length, lateral sprout thickness and days to full sprouting

Cultivar *	Tuber size	Length of dormancy period (days)	Number of sp /tuber	Lon sp length (mm)	Lon sp thickness (mm)	Lat sp length (mm)	Lat sp thickness (mm)	Days to full sprouting
Gera	v.small	109.83g	2.13f	14.87e	5.78	4.72f	0.66h	175.50i
	small	97.83ef	2.52ef	17.05e	7.08	6.07ef	1.16gh	159.80fgh
	medium	77.67c	2.47ef	25.70bc	9.05	7.98de	1.98fg	146.70def
	large	65.33b	2.87ef	32.77a	10.08	9.67cd	2.60def	144.20cde
Gudene	v.small	100.33fg	2.92ef	16.73e	6.95	5.99ef	1.75fgh	167.00ghi
	small	95.50ef	3.52de	18.00e	7.45	6.73ef	2.54ef	173.30hi
	medium	89.33de	4.80cd	19.10de	8.85	9.66cd	4.37c	164.20ghi
	large	84.83cd	6.30ab	20.25cde	9.47	11.25c	6.39b	158.30efg
Jalene	v.small	53.33a	3.00ef	19.67de	7.20	7.59de	3.21cde	138.50bcd
	small	51.67a	3.72de	24.18bcd	8.43	9.31cd	3.79cd	130.50abc
	medium	51.50a	5.15bc	27.12ab	9.54	13.93b	6.83b	126.20ab
	large	45.67a	6.78a	29.45ab	11.25	17.78a	8.38a	120.80a
CV		6.60	17.9	13.5	9.30	12.9	16.7	4.90
LSD		5.93	0.799	3.463	NS	1.38	0.705	8.65

Means with same letter(s) within a column are not significantly different at p<0.05 based on Tukey's test; V.small=very small; CV= Coefficient of Variation; LSD = Least Significant Difference; Lon=Longest; Lat=Lateral, sp=Sprout

Table 3: Interaction effect of cultivar and storage location on dormancy break, sprout number per tuber, longest sprout length, lateral sprout thickness and days to full sprouting

Cultivar*Storage Environment		Days to dormancy break	Sp no/tuber	Lon sp length (mm)	Lon sp thickness (mm)	Lat sp length (mm)	Lat sp thickness (mm)	Days to full sprouting
Gera	Elala	80.58	1.88c	21.85bc	9.77	9.77b	1.81d	146.17
	F.weyni	94.75	3.11b	23.34b	6.23	4.45d	1.39d	166.92
Gudene	Elala	87.75	3.59b	19.14cd	9.84	9.84b	4.69b	155.83
	F.weyni	97.25	5.18a	17.90d	6.52	6.97c	2.84c	175.58
Jalene	Elala	46.50	4.75a	23.08b	10.34	10.34b	6.38a	121.42
	F.weyni	54.58	4.58a	27.12a	7.88	13.97a	4.73b	136.58
CV		6.60	17.9	13.5	9.30	12.9	16.7	4.90
LSD		NS	0.565	2.449	NS	0.98	0.498	NS

Means with same letter(s) within a column are not significantly different at p<0.05 based on Tukey's test; CV= Coefficient of Variation; LSD = Least Significant Difference, Lon=Longest; Lat=Lateral, sp=Sprout

3.2. Longest sprout length

There was a highly significant difference for the interaction effect among cultivars and tuber sizes for the longest sprout length at week-28 (Table 2). At all storage environments and for all potato cultivars, the value for longest sprout length at week-28 consistently increased with increase in tuber size. The maximum value for sprout length (32.77 mm) was recorded by large tubers of the cultivar Gera. On the other hand, very small tubers of Gera cultivar had the shortest (14.87 mm) length of the longest sprout (Table 2).

Highly significant difference was also acquired for the interaction effect among cultivars and storage environment for the longest sprout length at week-28 (Table 3). The maximum value for sprout length (27.12 mm) was recorded by cultivar Jalene recorded from Gudene cultivar (17.90) at F.weyni. Of the three cultivars, Gudene recorded the shortest length of its longest sprout at all storage environments. From this result it could be recognized that the potato cultivars behave differently in different storage environments. The present result is similar with the result of Alemu *et al*. (2013) where in his experiment of storage of two varieties Guassa and Zengena for seven months, Guassa scored 1.6cm whereas Zengena scored 1.8cm of their longest sprout during the seven months storage period.

At both storage environments and for all potato cultivars, longest sprout length increased consistently throughout the storage period from week 20 to 28 weeks (Fig. 3). Regardless of their tuber size, Jalene cultivar recorder the highest length of its longest sprout at both storage environments; however, Gudene had the shortest length of its longest sprout (Fig. 3).

3.3. Longest sprout thickness

There was no significant difference for the interaction effect of cultivar and tuber size (Table 2). The thickness of the longest sprout consistently increased with increasing tuber size for all potato cultivars. This might be attributable due to the availability of more food reserves in large tubers than the smaller ones. In Principle, tubers with thick sprouts have advantages over those with thin sprouts since they have less probability of damage and breakage during transportation and planting.

Thickness of the longest sprout was not also significantly affected by the interaction effect of cultivar and storage environment the (Table 3). Generally the performance of all the three cultivars was lower for thickness of their longest sprouts under F.weyni storage environment. This could be associated with the cool storage temperature observed in the area during the experimental period.

Longest sprout thickness increased consistently throughout the storage period from week 20 to 28 weeks at both storage environments and for all potato cultivars (Fig. 4).

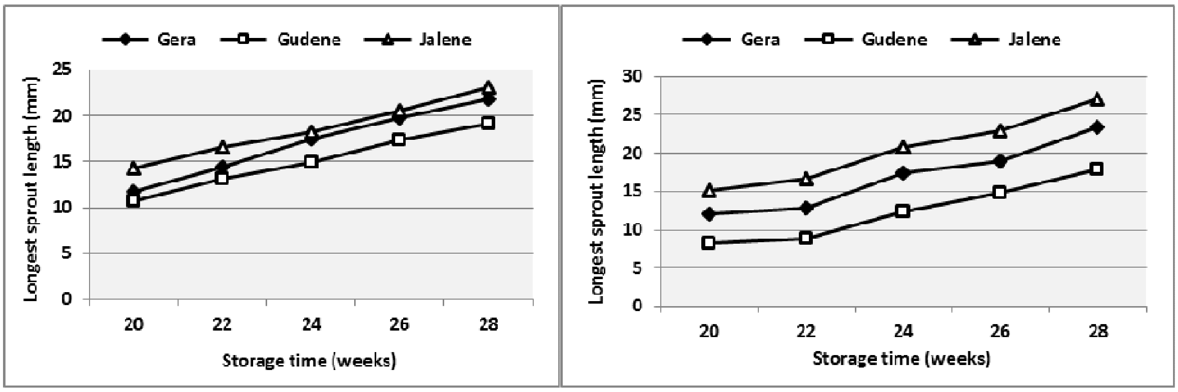


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Figure 3: Longest sprout length 20 to 28 weeks; where: (A) Elala environment; and (B) F.weyni environment

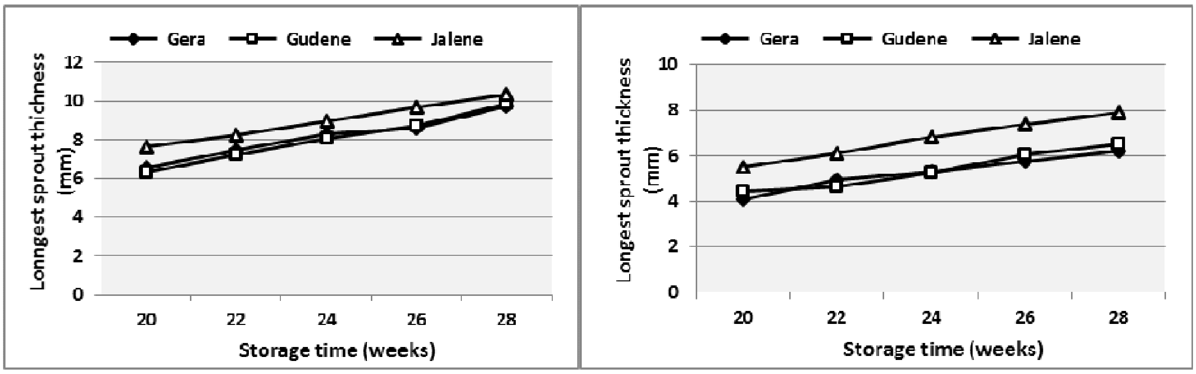

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Figure 4: Longest sprout thickness 20 to 28 weeks; where: (A) Elala environment; and (B) F.weyni environment

3.4. Length of lateral sprouts

The statistical analysis in Table 2 showed that length of lateral sprouts was significantly influenced by the interaction effect of cultivar and tuber size. There was a consistent increase of lateral sprout length with increase in tuber size for all cultivars at all storage environments. This could be due to the relatively more number of sprouts and shorter dormancy period in the large tubers than the smaller ones; because length and thickness the lateral sprout was recorded by taking the average length of three sprouts other than the longest ones from each tuber, the large tubers had more sprouts than the smaller ones. On the basis of the findings of the present study, large sprouts had more sprouts than the smaller ones hence they recorded higher lateral sprout length.

Generally irrespective of tuber size and storage environment, Gera cultivar had the lowest lateral sprout thickness. The reason for this is most probably the genetic variation among the potato cultivars in their sprouting behaviour. However, Jalene had the maximum lateral sprout length and thickness in all categories of tuber size. This could be due to the shorter dormancy period and the availability of a relatively more number of sprouts.

The maximum lateral sprout length (17.78 mm) was recorded from the large tubers of Jalene cultivar. Whereas the shortest (4.72 mm) sprout was recorded from the very small tubers of Gera.

There was a strong positive correlation between number of sprouts per tuber and length of the lateral sprouts (r = 0.45) indicating that the presence of more number of sprouts per tubers contributed the longest length of their lateral sprouts of same tubers (Table 4).

3.5. Thickness of lateral sprouts

There was significant different for both the two factor interactions. The interaction effect of cultivar and tuber size affected significantly the thickness of lateral sprouts. As it is depicted in Table 2, large and medium tubers of Jalene score the thickest sprouts (8.38 and 6.83 mm respectively); however the very small tuber of Gera scored the thinnest sprout (0.66 mm) followed by small tubers of the same cultivar(1.16 mm). Generally for all potato cultivars, lateral sprout thickness increased with increase in tuber size. This could be due to the relatively more number of sprouts and shorter dormancy period in the large tubers than the smaller ones.

There was also significant difference for the interaction effect of cultivar and storage environment in respect of their lateral sprouts thickness. Of all the three cultivars, Jalene scored the maximum lateral sprout thickness at both storage environments (6.83mm at Elala and 4.73mm at F.weyni). This could be due to the genetic variation among the potato cultivars in their sprouting behaviour; i.e. Gera had an apical dominance characteristic and thus had the lowest sprouts number per tuber. All potato cultivars scored the highest sprout thickness at Elala storage environment than at F.weyni (Table 3).

There was also a strong positive correlation (r = 0.72) between number of sprouts per tuber and thickness of the lateral sprouts which indicates thickness of lateral sprouts increased with increase in the number of sprouts per tuber (Table 4).

3.6. Days to reach full sprouting

There was a highly significant (P<0.01) difference for the interaction of cultivar and tuber size; however there was no significant difference for the interaction of cultivar and storage environment in respect of days to full sprouting. From Table 2, it could be seen that for all potato cultivars, the number of days to reach full sprouting level increased with decreasing tuber size which implies that the bigger tubers were ready for planting earlier than the smaller ones (Table 2). Large tubers of Jalene reached their full sprouting stage in 120.80 days, however very small tubers of Gera took 175.50 days to be ready for planting (Table 2). Regarding the potato cultivars, Jalene reached its full sprouting stage earlier (120.80 to 138.50 days) than the other cultivars (Table 2). All the potato cultivars reached their full sprouting stage earlier at Elala storage location than at F.weyni; even though there was no significant difference for the interaction effect of cultivar and storage environment (Table 3).

Table 4: Correlation of different parameters

Parameters	Codes							
Days to dormancy break	1	-						
Days to full sprouting	2	0.87^{**}	-					
Lat sprouts length	3	-0.61^{**}	-0.61^{**}	-				
Lat sprouts thickness	4	-0.63^{**}	-0.61^{**}	0.68^{**}	-			
Lon sprout length	5	-0.62^{**}	-0.49^{**}	0.54^{**}	0.33^{**}	-		
Lon sp thickness	6	-0.58^{**}	-0.66^{**}	0.62^{**}	0.66^{**}	0.50^{**}	-	
Sprout number per tuber	7	-0.30^{**}	-0.21^{*}	0.45^{**}	0.72^{**}	0.18	0.19	-
		1	2	3	4	5	6	7

4. Conclusions and recommendations

Cultivars differed in their dormancy period and sprouting characteristics. Of the three cultivars, Jalene ended its dormancy period earlier than the other cultivars. The number of days for dormancy break increased with decreasing tuber size which implies that the bigger tubers break their dormancy earlier than the smaller ones. Regarding the storage environment, all cultivars and tuber size levels had longer dormancy period at F.weyni.

Jalene cultivar also had more number of sprouts than the others. However Gera cultivar scored the lowest number of sprouts per tuber; even at the end of the storage period, it had less than three sprouts per tuber which clearly showed this cultivar exhibited apical dominant behaviour.

Tuber size categories affected dormancy period and sprouting characteristics. The large tuber size categories performed well in their sprouting characteristics, i.e. sprout number per tuber, length and thickness of the longest sprout, length and thickness of lateral sprouts increased with increased in tuber size. The very small and small tubers had inferior sprouting characteristics. Storage environment also affected dormancy and sprouting characteristics. All cultivars had shorter dormancy period and reached their full maturity stage earlier when stored at Elala storage environment.

Storage time also affected dormancy period and sprouting characteristics. Sprout number per tuber, length and thickness of the longest sprout increased with increase in storage time. Moreover cultivar storage environment and storage time interaction effect observed on dormancy period and sprouting characteristics of the treatments. So based on the results of the experiment, the following ideas are recommended:

- The medium and large tuber size levels with a diameter of 41 mm to 65mm are recommended for seed storage.
- De-sprouting treatment is recommended for Gera cultivar.
- Seed tubers should be planted as soon as they reach at their physiological maturity stage.
- Potato tubers should be stored at warm storage environments when short term storage is desired; however they should be stored at cool environments for long term storage.

Generally storing medium (41-50 mm) and large (51-65 mm) size categories of potato tubers may have a paramount role for a sustainable quality seed supply. Further research with more environments and multiple seasons is suggested.

5. Acknowledgements

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