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# Effect of Tuber Size, Storage Time and Storage Environment on Storage losses 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 selected potato cultivars under diffused light storage (DLS) structures in 2012/2013 in Tigray region, North Ethiopia. The treatments consisted of three environments, three potato cultivars and four tuber size categories arranged in Randomized Complete Block Design with three replications. Data pertaining to postharvest and sprouting characteristics were recorded for 28 weeks at monthly interval. Gudene and Jalene cultivars recorded more number of sprouts per tuber at Felegeweyni storage environment. In contrast Gera cultivar recorded few numbers of sprouts until week 28. All cultivars exhibited minimum physiological weight loss percentage and tuber decay at Felegeweyni storage environment. With increasing storage time, number of sprouts, percentage of physiological weight loss and decay of tubers increased. At Felegeweyni storage environment, large tuber size categories of all three potato cultivars had more number of sprouts per tuber, reduced tuber decay and lowest percentage of weight loss than in the other two storage environments. It is therefore recommended that for a sustainable quality seed supply, medium and large tuber size categories of potato should be stored at the cool highland environments.

**Key words:** dormancy, sprouting, potato, tuber size, diffused light storage

## INTRODUCTION

Potato is one of the major tuber crops which can be grown under both rain fed and irrigated conditions. Because of its high per unit area yield and nutritive value, potato production has increased over the past years in both the developing and developed countries faster than any other root and tuber crops (Jaspreet and Lovedeep, 2009). Baye and Gebremedhin (2013) reported that, the average potato productivity was only 7 tones/ha when the potential for small holder is around 25 tonnes/ha.

According to CSA (2007), in the region the total land allocated to potato production in 2006/07 main cropping season was estimated at 622 ha with a total production of 5,773.8 tonnes with an average yield of 9.29 tonnes/ha. Despite the limited nature of potato production in the country, about 30-50% of the annual potato produce is lost due to postharvest losses (Endale *et al*., 2008a). The limited availability of quality seed tubers is considered as one of the limitations to the expansion of potato production and cultivation in the country.

Physiological aging, internal age of the seed (tuber) resulting from biochemical changes, concerns the viability of tubers used for seed (Bohl *et al*., 1995). Respiration, water loss, sprouting, temperature and incidence of pests and diseases are the biochemical processes that affect the weight loss, quantity and quality of tubers during storage (Pinhero *et al*., 2009). Burton and Hartmans (1992) also added that the main causes of storage losses are respiration, evaporation of water from tubers, and spread of diseases.

Since different storage areas experience different temperature and relative humidity conditions, it has a great role in the quality of the stored potato tubers (Abeygunawardena *et al*. 1964). Besides other factors, environment of storage has a predominant effect on the loss in weight of potato tubers. 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. Higher relative humidity favours sprout growth and this is more pronounced at higher temperature; higher $CO_2$ concentration also favours sprout growth (Pinhero *et al*., 2009).

Storage diseases cause tuber decay in storage and this decay affects seriously the tubers quality. According to Endale *et al*. (2008a), post-harvest attack by microorganisms can cause a serious loss. Post-harvest diseases can start prior to harvesting in the field, at or following harvesting through wounds. During the storage of potatoes, temperature and disease infestation are two most important factors that influence the respiration rate, consequently the shelf life of the tubers. The use of quality seed of an improved variety is a key to increase the productivity of a potato crop (Berga *et al*., 1994). However, in Ethiopia chronic shortage of clean seed potato is still the major constraint to potato production and to the adoption of new and improved potato varieties (CIP, 2011). As a result, much of the seed potato requirement has been filled by the informal seed potato system; where seed tuber is produced and distributed by the farmers themselves without any technical support from other Non Governmental Organizations (NGOs) and breeding centres (Adane *et al*., 2010). The informal seed potato system covers 98.7% of the seed tubers required for planting (Endale *et al*., 2008a). The seed tubers supplied by this system are inferior in quality because the farmers consider seed tubers as a by-product of the ware tuber.

The increasing trend in potato production and consumption in the region demands sustainable supply of better quality seed tuber that is required for planting of the crop under both irrigation and rain fed where possible. However, less emphasis had been given to the quality aspect of seed potato produced even though the shortage of quality seed has been identified as the most critical problem in the potato production in the country. Therefore, this study was conducted to produce information that will contribute to improvements in the supply and handling of potato seed tuber in the Tigray region in particular and the country in general.

**Specific objectives**

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 seed tuber quality of selected potato cultivars.

## MATERIALS AND METHODS

The experiment was conducted from September 2012 to March 2013 under diffused light storage (DLS) structures at Debreberhan, Ilalla and Felegeweyni in the Tigray Region, Northern Ethiopia. Detailed description and geographical environment of the experimental areas is shown in Table 1 and Figure 1.

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.

**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 (°C) | Av Max Temp (°C) |
|---|---|---|---|---|---|---|
| Debreberhan | Hawzien | 13.913° N | 39.472° E | 2100 | 10.1 | 27.3 |
| Ilalla | 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.*

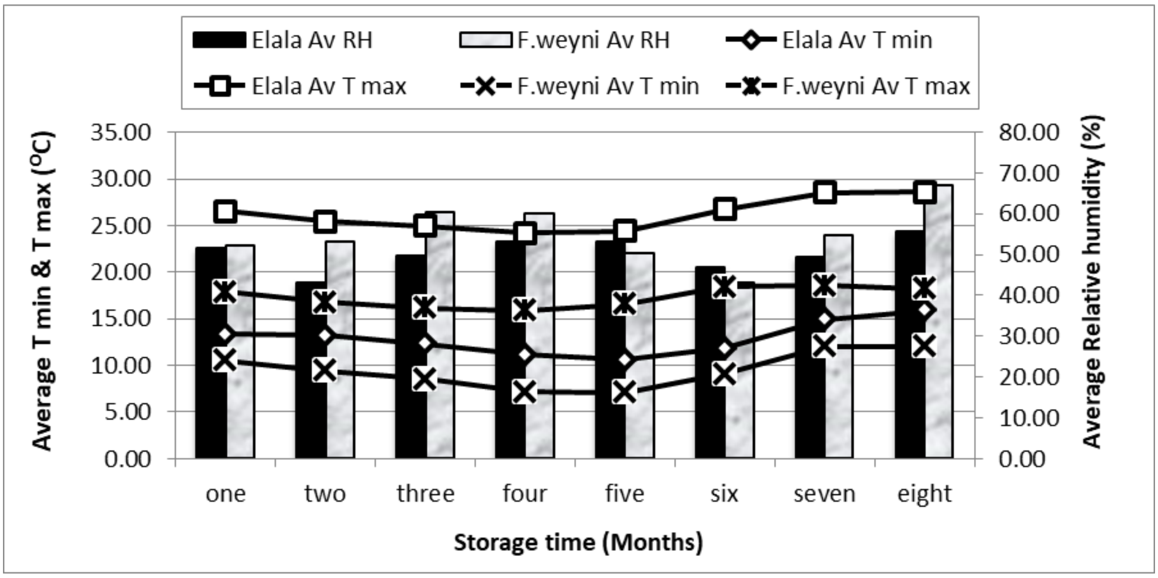


**Figure 1: Average maximum and minimum temperatures; and relative humidity from the data logger inside the DLS at Ilalla and Felegeweyni storage sites during the entire storage period.**

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$^2$).

The potato tubers were collected from a Seed Producer Cooperative at Felegeweyni. After curing, four kilograms of cured potato tubers from each cultivar, were graded into four tuber size ranges based on tuber diameter (very small (20-30 mm), small (31- 40 mm), medium (41-50 mm) and large (51-65 mm). Tuber diameter was determined using a manual Calliper.

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. Each treatment combination (cultivar x tuber size) was randomly assigned in the compartments. Weekly tuber weight measurements for each treatment combination were performed using a sensitive balance while maximum care was taken to prevent sprout breakage. Weight loss at 80% sprouting was taken when each tuber has at least one sprout longer than 15mm. The final weight of the tubers was taken during the 28$^{th}$ week of the experiment period in order to calculate the final weight loss percentage at the end of the experiment period.

Tuber decay assessment was carried out every two weeks in order to check if there were any decaying tubers. Each decaying tuber in each treatment combination was discarded after recording its weight. Then at last the percentage of the decayed tubers from each of the treatment combinations was calculated by summing up the weight of all discarded tubers and dividing to the original weight (4 Kg) and multiplying it by 100. The decay causing organisms were identified in plant pathology laboratory under the microscope using identifications keys.

**Table 2: Temperature and Relative humidity records from the nearby meteorology stations at Hawzien, Mekelle and Atsbi wereda towns.**

| Station | Average Temperature & Average RH | Storage month | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Month-1 (Sep) | Month-2 (Oct) | Month-3 (Nov) | Month-4 (Dec) | Month-5 (Jan) | Month-6 (Feb) | Month-7 (Mar) |
| Hawzien (Debreberhan) | Av. max Temp | 27.4 | 27.0 | 26.6 | 26.8 | 27.0 | 29.2 | 28.7 |
| | Av. min Temp | 11.0 | 8.5 | 9.2 | 6.2 | 6.9 | 5.9 | 10.0 |
| | Daily RH | NA | NA | NA | NA | NA | NA | NA |
| Mekelle (Ilalla) | Av. max Temp | 26.1 | 26.4 | 26.0 | 25.2 | 26.8 | 27.8 | 28.3 |
| | Av. min Temp | 14.3 | 11.0 | 11.5 | 8.6 | 9.0 | 8.7 | 12.3 |
| | Daily RH | 67 | 49 | 62 | 63 | 65 | 54 | 56 |
| Atsbi (Felegeweyni) | Av. max Temp | 19.9 | 18.4 | 18.0 | 18.3 | 19.5 | 21.8 | 19.7 |
| | Av. min Temp | 9.8 | 8.4 | 7.9 | 5.8 | 6.6 | 6.1 | 7.6 |
| | Daily RH | 55 | 55 | 70 | 57 | 48 | 40 | 49 |

*Source: Ethiopian meteorology agency, Mekelle branch; NA: Not Available*

To monitor the status of the temperature and relative humidity in the storage structures, a temperature and relative humidity data logger (HOBO U10-003) was installed at each storage structures. The data logger was adjusted to record the storage temperature and relative humidity every hour throughout the storage period inside the DLS. HOBO ware software (version 3.2.1, 2011) was used for the logger operation. Then the data were transferred to Excel program and then the minimum, maximum and average daily and monthly data were calculated and averaged over monthly intervals (Figure 1). Unfortunately the data were available only for Ilalla and Felegeweyni storage structures; as the data logger at Debreberhan had failed to record the data because of some interruption. Temperature and relative humidity data were also collected from the nearby meteorology stations in each respective wereda towns for the seven months period (Table 2).

For analysis the data were subjected to Analysis of Variance (ANOVA) using statistical software program (Gen-stat Version 13). Mean separation were made where the treatments differed significantly. Correlations analysis was also done in order to know the relationship among the response parameters. Besides to the ANOVA, repeated measurement analysis has also been made for those data which were taken repeatedly (number of sprouts per tuber and weight loss) in order to show the variation of the effects through time.

## RESULTS AND DISCUSSIONS

### *Time to 80% sprouting*

The analysis of variance presented in Table 3 revealed that there was a significant difference for all the main and interaction effects including the interaction effect of potato cultivar, tuber size and storage environment on the time to 80% sprouting. Number of days to 80% sprouting decreased with increase in tuber size for all potato cultivars at all storage environments indicating the large tubers reached their 80% sprouting earlier than the smaller ones. The shortest time to 80% sprouting was recorded from large tuber of Jalene cultivar (118.0 days) kept under Debreberhan environment. On the other hand, maximum number of days was elapsed (198.7 days) by small tubers of Gera cultivar stored at Felegeweyni storage site. The cultivar difference in combination with the tuber size difference had affected the treatments to behave differently. Similar result was reported by Abeygunawardena *et al.* (1964); the larger tuber sizes attained the 80% sprouting in less than 70 days where as those smaller ones took more than 100 days.

The three potato cultivars differed significantly for the time they become ready for planting. At all storage environments Jalene reached the 80% sprouting in an average of less than 150 days, however, Gera and Gudene took an average of 174 and 188 days respectively to reach the same degree of sprouting. This result is in agreement with the finding of Abeygunawardena *et al*. (1964). He found that of the two varieties, Tedria reached the 80% sprouting in 74 days while tubers from Gineke variety reached in 100 days to reach that same stage. For all potato cultivars, the number of days to reach 80% sprouting was increased as the environment changes from Debreberhan to Ilalla and Felegeweyni. The relatively warmer storage temperature at Debreberhan and Ilalla might have encouraged the potato cultivars to reach this stage earlier (Table 2 and Figure 1).

***Number of sprouts per tuber at 80% sprouting and week-28***

The interaction effect of potato cultivar, tuber size and storage environment revealed significant difference for the number of sprouts per tuber at 80% sprouting and at week-28 (Table 3). Number of sprouts per tuber increased progressively with increase in tuber size for Gudene and Jalene cultivars kept under all storage environments. However, for cultivar Gera, the number of sprouts decreased (with some exceptions) with increase in tuber size (Table 3). This may be due to the apical dominance characteristics of the particular cultivar. The duration of apical dominance as well as the number of sprouts per tuber is a varietal characteristic (Van Es and Hartmans, 1987). Since the 80% sprouting period was recorded as the time at which 80% of the tubers had a sprout length of 15 millimetres, the large and medium tuber sizes of the Gera varieties had the required length of their longest sprout earlier than the smaller tubers before the emergence of another sprout. This result shows that, even though these tubers had a 15 mm long sprout at this stage, it does not mean that they were ready for planting; because 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 storage environments and tuber size levels. Maximum number of sprouts was recorded from large tubers of the cultivar Gudene kept at Felegeweyni storage site (6.1). However it was statistically the same with medium tubers of Gudene and large tubers of Jalene at the same storage environment. Moreover the result was the same with the number of sprouts observed from large tubers of Gudene cultivar at Ilalla storage site. On the other hand, lowest number of sprouts was recorded from the small and large tubers of the Gera cultivar (1.23) under Debreberhan storage environment.

As it is depicted in Table 3, the number of sprouts per tuber increased progressively with increase in tuber size for all cultivars under all storage environments (small tubers of Gera kept at Debreberhan environment and medium tubers of the same cultivar stored under Felegeweyni site are the only exceptions). There was also clear difference among the cultivars in terms of their number of sprouts; i.e. Gera cultivar had the lowest number of sprouts per tuber of the three potato cultivars at all storage environments and at all tuber size categories. The maximum number of sprouts (7.10) was scored by large tubers of Gudene cultivar at Felegeweyni storage environment. This may be due to the high food reserve in the large sized tubers than the smaller ones. On the other hand minimum number of sprouts (1.43) was recorded from small tubers of the cultivar Gera under Debreberhan storage site. 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).

At the end of the storage period, all tuber size categories of the cultivar Gera had less than three sprouts per tuber (the large and small tubers stored at Felegeweyni are the only exceptions). 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. 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. Per the recommendation of Hollota Agricultural Research Centre (HARC) unpublished seed potato training manual, to obtain a good yield and optimum tuber size, a tuber to be planted should have at least three vigorous sprouts that are 15 mm to 20 mm long. 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 $28^{th}$ week of storage at all storage environments.

**Table 3: Interaction effect of cultivar, tuber size and storage environment on sprout number per tuber at 80% sprouting and sprout number per tuber at week-28**

| Environment | Cultivar | Tuber size | Time to 80% sprouting (days) | Sprout No./tuber at 80% sprouting | Sprout No./tuber at week-28 |
|---|---|---|---|---|---|
| Debreberhan | Gera | Very small | 177.67 $^{mno}$ | 1.87 $^{g-k}$ | 2.03 $^{mno}$ |
| | | Small | 148.00 $^{c-i}$ | 1.23 $^{k}$ | 1.43 $^{o}$ |
| | | Medium | 137.67 $^{b-e}$ | 1.27 $^{k}$ | 2.00 $^{mno}$ |
| | | Large | 130.67 $^{abc}$ | 1.23 $^{k}$ | 2.73 $^{j-o}$ |
| | Gudene | Very small | 179.00 $^{m-p}$ | 2.07 $^{f-k}$ | 2.17 $^{l-o}$ |
| | | Small | 158.33 $^{g-l}$ | 2.63 $^{e-k}$ | 3.70 $^{f-l}$ |
| | | Medium | 147.00 $^{c-i}$ | 2.77 $^{e-k}$ | 4.27 $^{d-j}$ |
| | | Large | 152.67 $^{e-k}$ | 3.23 $^{c-j}$ | 5.57 $^{a-e}$ |
| | Jalene | Very small | 158.00 $^{g-l}$ | 2.43 $^{e-k}$ | 3.17 $^{h-n}$ |
| | | Small | 150.33 $^{d-j}$ | 2.63 $^{e-k}$ | 3.53 $^{g-m}$ |
| | | Medium | 135.67 $^{b-e}$ | 3.47 $^{c-i}$ | 4.73 $^{b-h}$ |
| | | Large | 118.00 $^{a}$ | 3.00 $^{d-k}$ | 5.30 $^{b-f}$ |
| Ilalla | Gera | Very small | 198.00 $^{q}$ | 1.80 $^{h-k}$ | 1.73 $^{no}$ |
| | | Small | 165.67 $^{j-m}$ | 1.63 $^{ijk}$ | 2.03 $^{mno}$ |
| | | Medium | 152.33 $^{e-j}$ | 1.77 $^{h-k}$ | 2.37 $^{k-o}$ |
| | | Large | 134.33 $^{a-d}$ | 1.47 $^{jk}$ | 2.40 $^{k-o}$ |
| | Gudene | Very small | 188.00 $^{opq}$ | 2.73 $^{e-k}$ | 2.93 $^{i-o}$ |
| | | Small | 185.00 $^{n-q}$ | 2.93 $^{e-k}$ | 3.03 $^{i-o}$ |
| | | Medium | 172.33 $^{l-o}$ | 3.57 $^{c-h}$ | 4.47 $^{c-i}$ |
| | | Large | 163.00 $^{i-m}$ | 4.87 $^{a-d}$ | 6.13 $^{ab}$ |
| | Jalene | Very small | 170.00 $^{k-n}$ | 2.60 $^{e-k}$ | 2.97 $^{i-o}$ |
| | | Small | 151.00 $^{d-j}$ | 2.93 $^{e-k}$ | 4.20 $^{d-j}$ |
| | | Medium | 138.33 $^{c-f}$ | 4.00 $^{b-e}$ | 5.00 $^{b-g}$ |
| | | Large | 120.33 $^{ab}$ | 3.83 $^{b-f}$ | 5.57 $^{a-e}$ |
| Felegeweyni | Gera | Very small | 195.67 $^{pq}$ | 2.83 $^{e-k}$ | 2.87 $^{i-o}$ |
| | | Small | 198.67 $^{q}$ | 3.33 $^{c-j}$ | 3.33 $^{h-n}$ |
| | | Medium | 160.00 $^{h-l}$ | 1.93 $^{g-k}$ | 2.87 $^{i-o}$ |
| | | Large | 144.00 $^{c-h}$ | 1.63 $^{ijk}$ | 3.37 $^{h-m}$ |
| | Gudene | Very small | 195.33 $^{pq}$ | 3.43 $^{c-i}$ | 3.43 $^{g-m}$ |
| | | Small | 188.00 $^{opq}$ | 3.73 $^{b-g}$ | 4.13 $^{e-j}$ |
| | | Medium | 186.00 $^{n-q}$ | 5.57 $^{ab}$ | 6.03 $^{abc}$ |
| | | Large | 183.67 $^{n-q}$ | 6.10 $^{a}$ | 7.10 $^{a}$ |
| | Jalene | Very small | 152.67 $^{e-k}$ | 2.73 $^{e-k}$ | 3.07 $^{i-n}$ |
| | | Small | 155.33 $^{f-l}$ | 3.03 $^{c-k}$ | 3.87 $^{f-k}$ |
| | | Medium | 143.00 $^{c-h}$ | 3.73 $^{b-g}$ | 5.57 $^{a-e}$ |
| | | Large | 142.00 $^{c-g}$ | 4.90 $^{abc}$ | 5.80 $^{a-d}$ |
| CV (%) | | | 2.60 | 15.4 | 12.90 |
| LSD (5%) | | | 17.87 | 1.74 | 1.46 |

*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.*

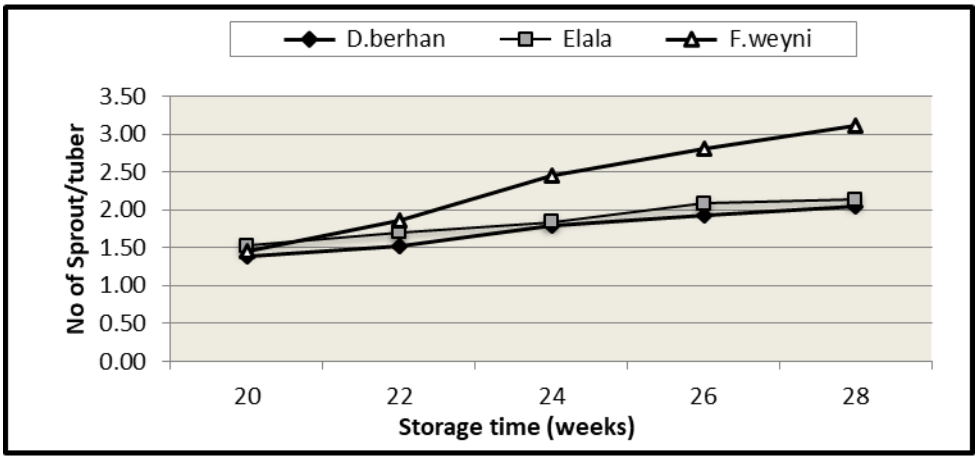


**Figure 2: Number of sprouts per tuber of Gera cultivar from week-20 to week-28 as affected by storage environment and storage time.**

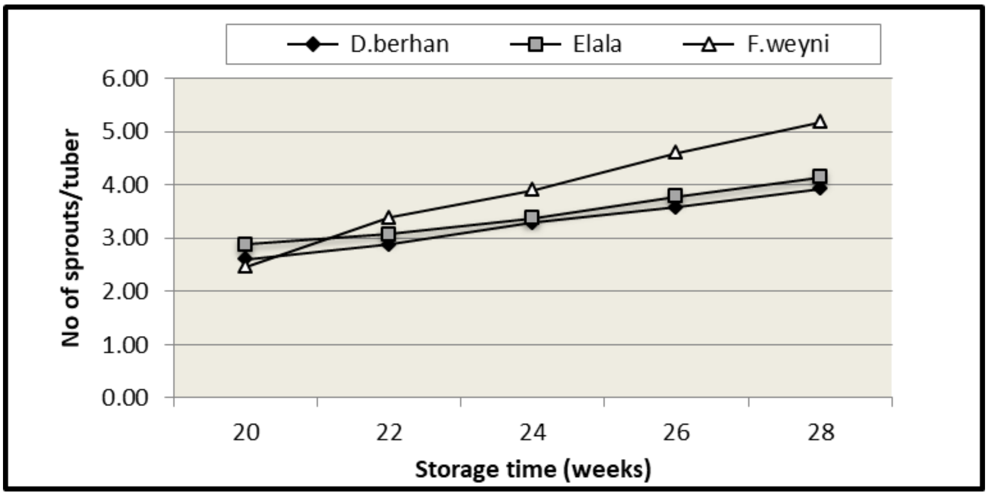


**Figure 3: Number of sprouts per tuber of from week-20 to week-28 as affected by storage environment and storage time of Gudene cultivar**

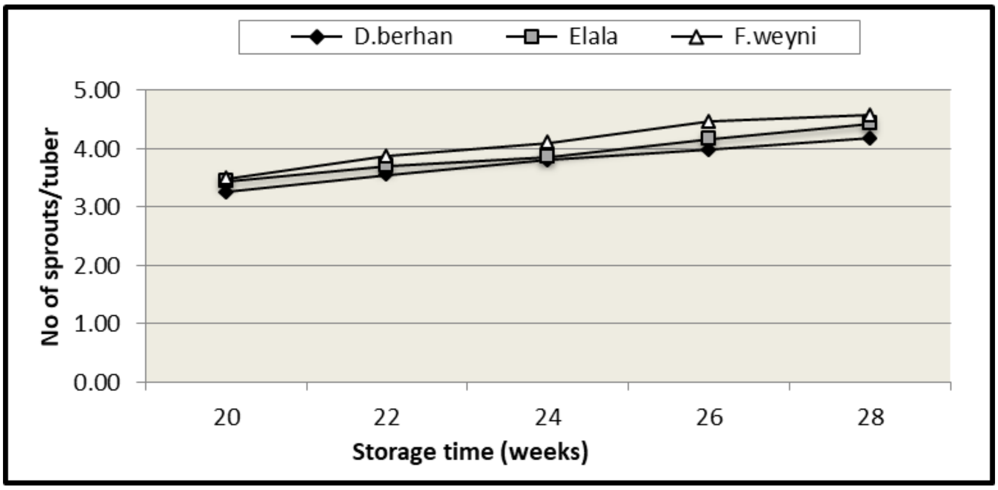


**Figure 4: Number of sprouts per tuber of from week-20 to week-28 as affected by storage environment and storage time of Jalene cultivar**

The repeated measures analysis revealed that the number of sprouts per tuber increased consistently with an increase in the storage duration for the number of sprouts per tuber during the 20, 22, 24, 26, and 28 weeks of storage period (Figures 2, 3 and 4). Gachango *et al*. (2008) and Alemu *et al*. (2013) also found a similar result that the number of sprouts per tuber increased with increase in storage duration.

For all tuber size levels of Gera and Gudene cultivars, number of sprouts was highest at Felegeweyni and lowest at Debreberhan (Figures 2 & 3). This may be due to the relatively lower storage temperature at Felegeweyni storage site. This is in alignment with the fact that exposure of seed tubers to lower temperatures during dormancy causes an increase in the number of sprouts per tuber after dormancy breaking (Struik, 2007). However there was a different scenario for cultivar Jalene; i.e. there was close similarity was observed among the storage environments even though there was high performance at Ilalla storage environment (Figure4). This clearly shows that performance of the same cultivar for number of sprouts may vary among different storage environments.

There was also a clear difference among the potato cultivars in terms of their sprout number per tuber. At all storage environments throughout the storage periods, Gera cultivar had the lowest number of sprouts per tuber. Most probably this was due to its apical dominance characteristics (Figure 2).

***Percentage of weight loss at 80% sprouting***

There was a highly significant (P<0.01) interaction effect among cultivar, tuber size and storage environment for the percentage of weight loss at 80% sprouting (Table 4). Tubers stored under the cooler environment of Felegeweyni incurred minimum weight loss than those stored under the relatively warmer areas of Debreberhan and Ilalla storage environments. Minimum weight loss (7.09%) was scored from the large tubers of Gera cultivar kept under Felegeweyni storage environment. On the other hand maximum loss in weight (55.69%) was incurred by the large tubers of Jalene cultivar kept under Ilalla storage environment. But it was significantly the same with that of the very small and medium tubers of the same cultivar at the same storage site as well as large tubers of the same cultivar kept under the storage environment of Debreberhan.

For Gera and Gudene cultivars, the percentage of weight loss decreased progressively with the increase in tuber size. The large tuber sizes of both cultivars incurred the minimum percentage of loss in weight. This result is in agreement with the result of Abeygunawardena *et al*. (1964) where he found that the amount of weight loss increases as the tuber size decreases and the smaller tuber sizes lost the highest percentage. Whereas in the case of Jalene cultivar, the highest percentage of weight loss was recorded by the large tuber size levels followed by the very small ones. This could be most probably due to the sensitivity of Jalene cultivar to decay in the storage. Since the decayed tubers were discarded every time, due to the heavy weight of each tubers discarded at a time, the percentage of the discarded tubers will be added to the lost in weight and then the percentage of loss would be more.

There was great variability among the cultivars in their performance of weight loss in the DLS. As clearly depicted in Table 4, the extent of weight loss increased from Gera to Gudene and was highest for Jalene. At the 80% sprouting, large tuber of Gera cultivar incurred only 7.60% of weight loss, while the amount of loss incurred by Jalene reached up to 36.94%. This could be due to the shorter dormancy period and the presence of more number of sprouts at this sprouting stage. The presence of multiple sprouts is usually accompanied by greater weight loss of sprouted tubers, thus this later parameter should be taken in to account in multiple sprouting cultivars for deciding best storage conditions or storage period (Carli *et al*., 2012). Another probable reason could also be the difference among the cultivars in their periderm characteristics. The results of the present study are in conformity with that of Endale *et al*. (2008b) who while comparing seven varieties found that the percentage of weight loss varied from 12.4 % in the variety Tolcha to 33.1 % in the variety Wochecha.

All the three cultivars had minimum amount of weight loss at Felegeweyni storage environment. Even cultivar Jalene could be stored at Felegeweyni with relatively less loss in weight until the end of the experiment period. This could be due to the relatively cool storage temperature and higher relative humidity at this storage area (Table 1 & Figure 1). In the seed potato industry this implies a great advantageous since the price of seed potato is higher in most of the production areas in the country. According to Endale *et al*. (2008b), the cost of seed potato covers more than 50% of the total production cost.

There was very strong positive correlation (r = 0.78) between weight loss at 80% sprouting stage and decay of tubers in storage indicating the higher the percentage of decayed tubers in the storage contributed more to the percentage of weight loss by the tubers (Table 5).

***Percentage of weight loss at week-28***

There was significant difference for the interaction effect of cultivar, tuber size, and storage environment for the percentage of weight loss during week-28 (Table 4). From the result it could be seen that the tubers stored at the cooler environment of Felegeweyni incurred minimum weight loss than those stored at the relatively warmer areas of Debreberhan and Ilalla. Minimum weight loss (12.46%) was scored from the large tubers of Gera cultivar kept under Felegeweyni storage site. Statistically the same percentage of loss in weight was scored by all tuber size levels of Gudene and Gera cultivars at Felegeweyni storage environment. Statistically the same weight loss percentage was also recorded from large tubers of Jalene cultivar at Felegeweyni; all tuber size levels of Gera cultivar at Ilalla; large, medium and small tubers of Gera at Debreberhan; and small and large tubers of Gudene at Debreberhan storage environment. On the other hand, maximum loss in weight (79.91%) was incurred by very small tubers of Jalene cultivar kept under Ilalla storage site, but not statistically different from all the remaining tuber size levels of the same cultivar at the same storage environment as well as large tubers of the same cultivar but at kept at Debreberhan storage environment.

For Gera and Gudene cultivars the amount of weight loss increased progressively from the very small tuber size towards the large tubers under all storage environments (medium and large tubers of Gudene at Debreberhan were the only exceptions). This may be due to the more surface area of the smaller tubers than the larger ones which is exposed to respiration and water loss. The variation in the periderm characteristics between the large and small tubers may also be another probable reason. Because, according to Pinhero *et al*. (2009), the periderm characteristic of the mature potatoes influences the rate of water loss under any water pressure deficit and freshly harvested immature tubers lose water more rapidly than mature tubers since they are more permeable than mature tubers. However for Jalene cultivar there was another scenario even though there was similar case at Felegeweyni, *i.e*. there was no significant difference among the tuber size cultivars in their weight loss percentage. This could be most probably due to the sensitivity of the particular cultivar to tuber decay coupled with its relatively short length of dormancy period. During the last time of the storage period (week-28), all the very small tubers of Gera, Gudene and Jalene cultivar and the small tubers of Jalene cultivar dried out to the level at which they cannot be used as seed at Debreberhan and Ilalla storage environments. The very small tubers of Jalene cultivar also dried out at Felegeweyni storage environment. This may be due to the respiration and weight loss from the limited food reserve of the smaller tubers. Stored tubers lose moisture (shrink) through respiration and evaporation because they are living organisms and produce heat through respiration (Sterrettt, 2009). Endale *et al*. (2008a) also reported similar result where he stored potato tubers in naturally ventilated storage for 120 days and observed mean tuber weight loss as high as 23% and due to excessive moisture loss the tubers were dry and they were not suitable for planting after 6 months.

During the end of the experiment period, there was a clear difference in percentage of weight loss among the three potato cultivars under all storage environments and tuber size levels. Generally of the potato cultivars, Jalene incurred maximum weight loss percentage at all tuber size levels and under all storage environments. However Gera had the lowest weight loss percentage at all storage environments and for all tuber size levels. This may be due to the cultivar difference in their periderm characteristics which is responsible for the respiration and transpiration which are among the most decisive factors for weight loss. The shorter length of dormancy period and the presence of more sprouts also could be another probable reason for the Jalene cultivar to incur more loss in weight. The presence of multiple sprouts is usually accompanied by greater weight loss sprouted tubers (Carli *et al*., 2012). According to Burton and Hartmans (1992), after sprouting sprouted tubers lose water 30-40 times more rapidly than un-sprouted potato tubers of the same surface area. According to Pinhero *et al*. (2009), from a particular sample of potato, the rate of water loss is proportional to the water pressure deficit of the surrounding air. The presence of multiple sprouts is usually accompanied by greater weight loss of sprouted tubers, (Carli *et al*., 2012).

Environment of storage had a pronounced effect on the percentage of loss in weight for all the potato cultivars and tuber size levels. All the potato cultivars and tuber size levels had a significant lower percentage of tuber weight loss under Felegeweyni storage environment (Table 4). This could be due to the relatively cool storage temperature and relatively higher relative humidity at this storage environment (Table 2 and Figure 1). Abeygunawardena *et al*. (1964) reported similar results to the present finding while studying the influence of storage environment on potato post harvest status at three environments, and reported that, environment of storage has predominant effect on the loss in weight of potato tubers.

**Table 4: Interaction effect of cultivar, tuber size and storage environment on weight loss at 80% sprouting, weight loss at week-28 and of decayed %**

| Environment | Cultivar | Tuber size | Weight Loss (%) at 80% Sprouting | Weight loss (%) at week-28 | Decay (%) |
|---|---|---|---|---|---|
| Debreberhan | Gera | Very small | 18.65 $^{abc}$ | 26.83 $^{d-h}$ | 7.94 $^{ab}$ |
| | | Small | 11.76 $^{ab}$ | 20.83 $^{a-g}$ | 4.25 $^{ab}$ |
| | | Medium | 8.66 $^{a}$ | 18.30 $^{a-f}$ | 3.37 $^{ab}$ |
| | | Large | 7.88 $^{a}$ | 17.87 $^{a-f}$ | 3.82 $^{ab}$ |
| | Gudene | Very small | 13.10 $^{ab}$ | 28.61 $^{d-h}$ | 3.01 $^{ab}$ |
| | | Small | 13.21 $^{ab}$ | 21.94 $^{a-g}$ | 2.04 $^{ab}$ |
| | | Medium | 18.14 $^{abc}$ | 26.17 $^{c-h}$ | 7.36 $^{ab}$ |
| | | Large | 15.32 $^{abc}$ | 23.03 $^{a-g}$ | 10.91 $^{b}$ |
| | Jalene | Very small | 32.07 $^{cde}$ | 57.90 $^{i}$ | 34.44 $^{de}$ |
| | | Small | 24.08 $^{a-d}$ | 56.68 $^{i}$ | 31.79 $^{d}$ |
| | | Medium | 26.35 $^{bcd}$ | 60.12 $^{ij}$ | 38.28 $^{de}$ |
| | | Large | 43.77 $^{ef}$ | 76.97 $^{k}$ | 43.04 $^{e}$ |
| Ilalla | Gera | Very small | 20.10 $^{a-d}$ | 24.42 $^{a-g}$ | 0.70 $^{a}$ |
| | | Small | 11.98 $^{ab}$ | 18.72 $^{a-g}$ | 0.43 $^{a}$ |
| | | Medium | 10.38 $^{ab}$ | 20.56 $^{a-g}$ | 1.00 $^{a}$ |
| | | Large | 7.83 $^{a}$ | 16.41 $^{a-d}$ | 0.42 $^{a}$ |
| | Gudene | Very small | 21.10 $^{a-d}$ | 30.10 $^{fgh}$ | 0.40 $^{a}$ |
| | | Small | 19.18 $^{abc}$ | 27.34 $^{d-h}$ | 1.25 $^{a}$ |
| | | Medium | 17.38 $^{abc}$ | 28.97 $^{e-h}$ | 1.55 $^{a}$ |
| | | Large | 16.78 $^{abc}$ | 31.05 $^{gh}$ | 5.78 $^{ab}$ |
| | Jalene | Very small | 53.72 $^{f}$ | 79.91 $^{k}$ | 21.97 $^{c}$ |
| | | Small | 36.48 $^{de}$ | 74.74 $^{k}$ | 21.23 $^{c}$ |
| | | Medium | 46.72 $^{ef}$ | 72.23 $^{jk}$ | 31.65 $^{d}$ |
| | | Large | 55.69 $^{f}$ | 73.89 $^{k}$ | 39.28 $^{de}$ |
| Felegeweyni | Gera | Very small | 15.18 $^{abc}$ | 19.44 $^{a-g}$ | 0.00 $^{a}$ |
| | | Small | 9.02 $^{a}$ | 12.65 $^{ab}$ | 0.61 $^{a}$ |
| | | Medium | 8.06 $^{a}$ | 14.22 $^{abc}$ | 0.00 $^{a}$ |
| | | Large | 7.09 $^{a}$ | 12.46 $^{a}$ | 0.00 $^{a}$ |
| | Gudene | Very small | 19.31 $^{a-d}$ | 22.06 $^{a-g}$ | 0.00 $^{a}$ |
| | | Small | 12.16 $^{ab}$ | 16.48 $^{a-e}$ | 0.00 $^{a}$ |
| | | Medium | 13.73 $^{ab}$ | 19.94 $^{a-g}$ | 0.00 $^{a}$ |
| | | Large | 8.83 $^{a}$ | 13.47 $^{ab}$ | 0.00 $^{a}$ |
| | Jalene | Very small | 23.33 $^{a-d}$ | 37.91 $^{h}$ | 3.18 $^{ab}$ |
| | | Small | 18.32 $^{abc}$ | 31.09 $^{gh}$ | 2.09 $^{ab}$ |
| | | Medium | 13.01 $^{ab}$ | 25.14 $^{b-g}$ | 2.08 $^{ab}$ |
| | | Large | 11.38 $^{ab}$ | 24.24 $^{a-g}$ | 5.26 $^{ab}$ |
| CV (%) | | | 20.40 | 9.00 | 23.00 |
| LSD (5%) | | | 15.63 | 11.55 | 8.17 |

*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.*

*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.*

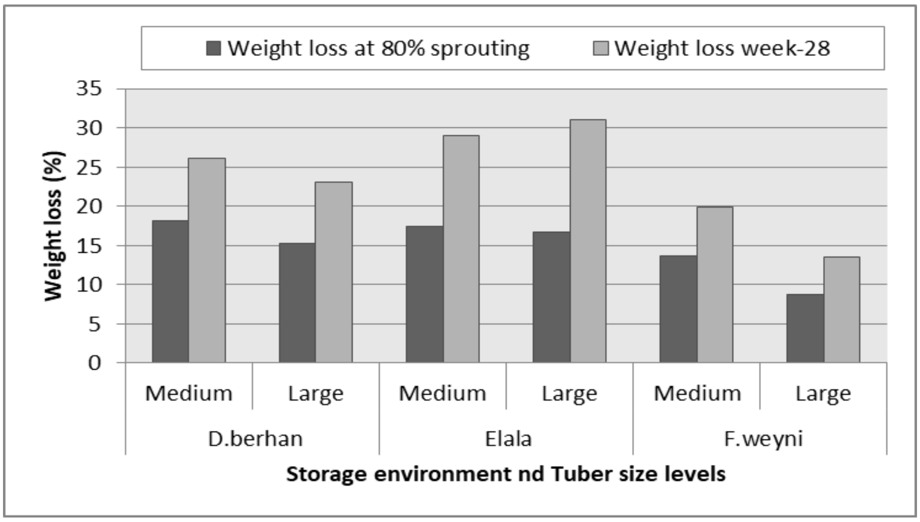


**Figure 5: Weight loss percentage at 80% sprouting and at week-28 storage periods for medium and large tubers of Gudene cultivar.**

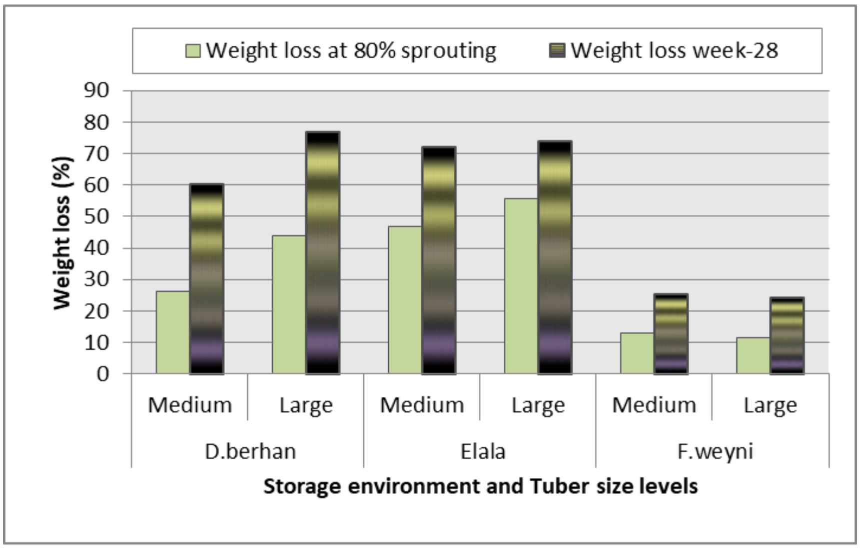


**Figure 6: Weight loss percentage at 80% sprouting and at week-28 storage periods for medium and large tubers of Jalene cultivar.**

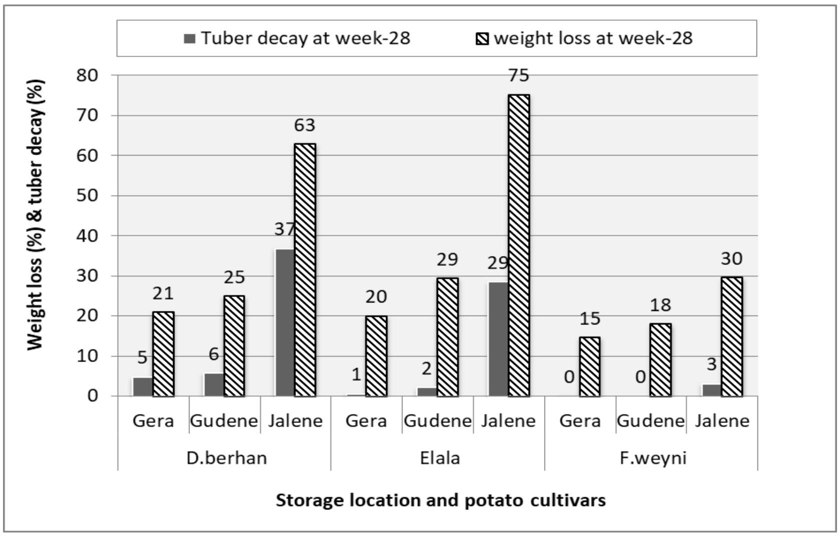


**Figure 7: The relationship between decay of tubers and weight loss percentage at week-28.**

**Table 5. Correlation of parameters**

| Parameters | T to 80% | NS-80% | NS-28 | WL-80% | WL-28 | Decay% |
|---|---|---|---|---|---|---|
| **T to 80%** | - | | | | | |
| **NS-80%** | 0.18 | - | | | | |
| **NS-28** | -0.18 | 0.88** | - | | | |
| **Decay%** | -0.53** | 0.10 | 0.268** | 0.78** | 0.89** | - |

*Where:*

- *T to 80% = time to 80% sprouting*
- *NS-80% = No of sprouts/tuber at 80% sprouting*
- *NS-28 = No of sprouts/tuber week-28*
- *WL-80% = weight loss % at 80% sprouting*
- *WL-28 = weight loss% week-28*
- *Decay = decay of tubers %*

There was conspicuous weight loss increase during the 28th week storage period than at the 80% of sprouting, especially for Jalene cultivar. So, greater amount of weight loss could be saved by taking out the medium and large tubers of Gudene and Jalene cultivars from the DLS at their 80% sprouting period; since at this period all the tubers were ready for planting at all storage environments (Figures 5 and 6).

***Percentage of decayed potato tubers in storage***

There was a highly significant difference (P<001) for the interaction effect among cultivar, tuber size and storage environment in terms of decay of the potato tubers in storage (Table 4). No tuber decay was recorded from all tuber size categories of Gera and Gudene cultivars (with the exception of small tuber of Gera). But it was significantly different only with all tuber size levels of Jalene cultivar under Debreberhan and Ilalla storage sites; as well as with the large tubers of Gudene at Debreberhan environment. The percentage of decayed tubers was the least for all potato cultivars and tuber size levels at Felegeweyni storage area; the maximum decay percentage at this storage environment was 5.26% from the large tubers of Jalene cultivar. However, the percentage of decay reached up to 39% and 43% for Jalene cultivar under Ilalla and Debreberhan storage environments respectively. The reason for this may be the relatively higher storage temperature at Ilalla and Debreberhan storage environments which aggravated the activity of decay causing micro organisms (Table 2 & Figure 1). During potato storage, high temperature facilitates the development of either spore contaminated or disease developed tubers (Fennir *et al*., 2005).

There was also a significant variation among the potato cultivars for the decay percentage during the storage time. Gera cultivar incurred the least tuber decay at all tuber size levels and at storage environments during the storage time, the maximum loss being 7.94% at Debreberhan site. However Jalene cultivar incurred the highest percentages of tuber decay.

Decay of potato in storage is largely governed by tuber injury and pest and disease attack. During the experiment period, decay of the tubers was caused due to the disease incidence in the storage area. In the pathology laboratory, two types of disease were identified at Debreberhan and Ilalla storage environments. They were soft rot caused by a bacterial pathogen called *Erwinia carotovora* and dry rot which is caused by a fungal pathogen called Fusarium spp. As visually observed soft rot was more destructive than dry rot and most spoilage and decay was caused by this disease. At Debreberhan and Ilalla storage environments, Jalene was the most susceptible cultivar for soft rot and dry rot. However, at Felegeweyni storage environment there was very few decay of tubers caused by aphids. Dry rot and soft rot diseases are more active at high temperature areas. According to Barbara, (1998), the optimum temperature for soft rot is from 60$^{o}$F to 85$^{o}$F; and dry rot is also more active at temperatures greater than 50$^{o}$F. This result agrees with Abeygunawardena *et al*. (1964), which in his experiment found that, the storage diseases were more destructive at the warmer environments but at the cool climate of Sita Elya, there was minimum decay of tubers.

The percentage of decay of potato tubers contribute more for the weight loss percentage, since the amount of this loses was added to the loss in weight (Figure 7). As the potato tubers become decayed, the amount of loss by respiration and transpiration will be increased so it has also an indirect effect on the loss in weight at the 28th period of storage. The percentage of tuber decay was relatively lower for Gera and Gudene cultivars. However the amount of tuber decay incurred by Jalene cultivar ranges from 18.37% for the small tuber size to 29.19% for the large tuber size.

The large tubers of Jalene cultivar incurred the higher amount of tuber decay. This could be due to the periodic rejection of the potato tubers when they were decayed. The weight of the tubers rejected will be more when one tuber is rejected from the heavy large tuber. Whereas, in the case of the smaller tubers, the weight of a single tuber is so small, so discarding small tubers will not raise much the percentage of decay.

From the result at Table 4, it was observed that there was conspicuous reduced decay of tubers at Felegeweyni storage site than the other environments. Surprisingly, even cultivar Jalene could be stored with reduced amount of tuber decay for 28 weeks at Felegeweyni storage environment. This may be due to the cool storage temperature of the environment. Fennir *et al*. (2005) reported the development of disease on the spore-contaminated tubers could be slowed by storage at low temperatures, in contrast, high temperature facilitates the development of either spore contaminated or disease developed tubers.

There was very strong positive correlation (r = 0.89) between weight loss at week-28 and decay of tubers in storage indicating the higher the percentage of decayed tubers in the storage, the higher will be the percentage of weight loss (Table 5). As depicted in figure 7, those tubers with a greater amount of decay like Jalene exhibited huge amount of weight loss during the end of the experiment period. This could be due to the increased rate of respiration and transpiration of water from the decayed tubers.

## CONCLUSION

Cultivars differed in their dormancy period, storage loss and sprouting characteristics. Medium and large tubers of Gudene and Jalene cultivars scored more than 3 sprouts per tuber during the 80% sprouting stage. This implies that they became ready for planting during their 80% sprouting stage. In contrast, Gera cultivar had few numbers of sprouts until the end of the experiment period. In terms of storage loss, Gera and Gudene cultivars incurred relatively minimum weight loss and tuber decay. However cultivar Jalene had higher weight loss percentage and incurred maximum tuber decay.

Tuber size categories affected dormancy period, storage loss 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. Moreover relatively lower weight loss percentage was recorded by the large tubers for Gera and Gudene cultivars under all storage environments, even though there was no significant difference among the tuber size levels of Jalene cultivar at Debreberhan and Ilalla storage environments. The very small and small tubers had inferior sprouting characteristics and exposed for higher weight loss percentage: dried out during the end of the experiment.

Storage environment affected dormancy period, storage loss and sprouting characteristics. All cultivars had lower storage loss and sprouting characteristics at Felegeweyni storage environment. In a special case, Jalene cultivar showed best performance when stored at Felegeweyni storage environment than the other environments. Debreberhan and Ilalla storage environments are not preferred for long term seed potato storage.

Storage time affected dormancy period, storage loss and sprouting characteristics. Sprout number per tuber, length and thickness of the longest sprout increased with increase in storage time. Likewise weight loss and tuber decay percentage increased with increase storage time.

Cultivar, tuber size, and storage environment interaction affected dormancy period, storage loss and sprouting characteristics of potato tubers. Moreover cultivar, tuber size, storage environment and storage time interaction effect observed on dormancy period, storage loss 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.
- Those cultivars with short dormancy period should be stored at the cool storage environments.
- Potato tubers should be stored at cool storage environments when long term storage is desired.

Generally storing medium and large size categories of potato tubers at the cool highland environments may have a paramount role for a sustainable quality seed supply; and such areas should be given due attention in the further seed potato improvement strategy. Further research with more environments and multiple seasons is suggested.

**Competing interests**
Authors have declared that no competing interests exist.

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