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ARTICLE

Effect of Curing Period, Plant Hormone and On-farm Storage Methods on Physiological Losses of Potato (*Solanum tuberosum*) Tubers

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ARTICLE INFO

Article history

Received: 12 August 2022

Revised: 30 October 2022

Accepted: 9 November 2022

Published Online: 28 November 2022

Keywords:

Weight loss

Shriveling loss

Abscisic acid

ABSTRACT

This study was carried out to evaluate the role of curing period, exogenous Abscisic Acids (ABA) levels and on farm storage methods on the physiological quality losses of potato tubers during storage. The research was set out in a Split-Split-Plot Design (SSPD) with curing period allocated to the main plot while storage condition and ABA levels assigned to subplot and sub-sub-plot respectively. The treatments were replicated thrice and factorially combined to give a 4 × 3 × 3 experiment. Each treatment consisted of 20 potato tubers out which three were randomly selected and earmarked for data collection. Data on percentage physiological weight and shriveling losses were recorded fortnightly throughout the storage period whereas temperature, relative humidity and wind velocity were monitored weekly. Collected data were analysed using Analysis of Variance (ANOVA) appropriate to split-split plot design using Genstat. Means showing significant difference was separated using Least Significant Difference (LSD) at 0.05% level of probability. The results showed that, ABA levels had highly significant ($P \leq 0.01$) influence on both percentage physiological weight and shrinkage losses at 8 and 10 Weeks After Storage (WAS) respectively while percentage shrinkage loss was significantly ($P < 0.05$) affected by ABA level at both 2 WAS and 12 WAS. There was also a highly significant ($P \leq 0.01$) interaction of curing periods and storage conditions on both percentage weight and shriveling loss at 8 WAS and 10 WAS respectively. Five days curing period, shaded pit storage and application of 4 ppm of ABA to potato tubers under ambient conditions had minimum physiological losses of potato tubers in the study area.

1. Introduction

Potato (*Solanum tuberosum* L.) is placed as the fourth major food crop worldwide after wheat, rice and corn and it is also the most important root crop in the world [1]. Potato is called the “king” of vegetable [2] due to its

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DOI: https://doi.org/10.55121/nc.v1i2.41

delicacy and nutritional values [3]. It is also considered as the most important crop in the fight against food insecurity, malnutrition and climate change [4]. Because of the importance attached to potato in world food security, the United Nation declared 2009 as the year of potato and this was further buttressed by the statement of the former Director General of FAO (Jacques Diouf) that "potato is on the frontline in the fight against world hunger and poverty" [5].

In spite of the nutritional importance of potato it is beyond the reach of a common man in Nigeria due to the non-availability of the produce all-year-round caused by poor storage and postharvest handling. The postharvest losses of potato tubers incurred in the country is enormous [6], postharvest losses of horticultural produce potato are estimated at 30%-50% in developing countries from farm gate to fork [8]. These losses are caused majorly by postharvest factors which require urgent effort to alter the trend and reduce global food insecurity.

Lack of cooling technologies and limited or unaffordable access to power supply which reduced storability of most perishable produce such as potato have forced farmers to focus attention on the on-farm storage technologies because of the numerous advantages as enumerated by Paul *et al.* [7] that include, cheap, zero energy input, affordability, availability of material for construction, ideal for both short and long-term storage to overcome periodic glut and distressed sale by farmers. As such traditional or on-farm storage methods should not be disregarded since they have developed overtime from practical experience with the particular crop cultivars grown in the areas and are in alignment with the local environmental conditions as earlier observed [8]. The farmers in the study area don't know the correct curing period and storage method for a better storage of potato tubers and in addition, there is a need for an alternative methods for potato sprout control during storage for potato more especially for potato tubers meant for organic and export markets where there is ban on the most widely spout suppressant Isopropyl N-(3-chlorophenyl) carbamate (CIPC) because of both health and environmental consequences and since sprouting is one of the major cause of physiological postharvest deterioration of potato tubers [9,10].

Many researchers have conducted a lot of work on effects of curing, storage method and dormancy suppression on the postharvest quality of potato but none of work focused on the present study area [11-17]. Furthermore, the studies employed advanced modern technologies which are not available in the study area or beyond the reach of ordinary farmers in the study area. Moreover, cool storage facilities even available have an adverse effect on the processing quality of potato. This study therefore, aim to determine the impact of the different on-farm storage methods that evolved overtime among the local farmers, exogenous Abscisic Acid (ABA) and best curing period that would increase potato shelf life in the study area.

2. Materials and Methods

The study was done at the teaching and research farm of Food and Agriculture Tree Crop Plantation (FAO/TCP) of Adamawa State University, Mubi. The town lies between latitude 10° 06'-10° 29' north of the Equator and longitude 13° 07'-13° 30' east of the Greenwich Meridian with an altitude of 696 m above sea level and it is also located within the Northern Guinea Savannah agro-ecological zone [18-20]. It has a mean annual rainfall of 1000 mm with a distinct dry season which usually begins in October and ends in April, while the raining season begins in May and ends in September or sometimes in October. It has a mean maximum temperature of 32.1 °C and a minimum of 18.5 °C.

The experiment was carried out in 2019/2020 dry season and fresh matured dry season potato (Marabel cv) tubers produced in Kwaja (900 m above sea level) village in Mubi South Local Government Area of Adamawa State and Abscisic Acid with 95% purity purchased from Zhengzhon Panpan Chemical Co. Ltd, China were used for the study.

The potato tubers were subjected to three curing periods, namely; Zero (control), three, Five and Seven days. Plant Hormone (Abascisic Acids) at the following rates was applied; 0 ppm (control), 2 ppm and 4 ppm. The following storage methods were adopted for the research: storage on concrete floor (control), heap storage between alternate layers of paddy straw and shaded pit (50 × 50 × 70 cm) storage with alternate layers of paddy straw under shade.

The experiment was laid out in a Split-Split-Plot Design (SSPD) with curing period assigned to the main plot while storage condition and ABA level allotted to subplot and sub-sub-plot respectively. Each treatment was replicated three times. The experiment consisted of three factors (curing period, storage conditions and ABA levels) that were factorially combined to give a 4 × 3 × 3 factorial experiment with 36 treatments. Each treatment consisted of 20 potato tubers out of which three were randomly selected and labeled for data collection. Data were taken on percentage physiological weight loss and percentage shrinkage loss fortnightly whereas temperature, relative humidity and wind velocity were monitored weekly *a. Determination of environmental conditions*

Data on environmental conditions such as temperature, relative humidity and wind velocity of the storage environment were monitored for 12 weeks of storage (January – May, 2020) using a digital automatic integrated weather station located in the research farm.

b. Determination of Percentage Physiological Weight Loss (%PWL)

Measurements of weight were done using digital sensitive electronic scale model SF-400 made in China, and the difference between original and final weights was calculated. The percentage physiological weight loss was obtained using Equation (1) as described by Ahmed [21], Ahmed *et al.* [22].

$$\% \, physiological \, weight \, loss = \frac{original \, weight - new \, weight \times 100}{original \, weight} \quad (1)$$

c. *Determination of percentage physiological shrinkage*

The diameter of the tuber was measured with digital Vanier caliper at the beginning of the experiment and subsequently fortnightly, the diameter determination was done by measuring at a marked point with a permanent marker which serve as a reference point for subsequent measurements. The difference between the initial and final measurement are used to determine the percentage shrinkage using Equation (2) as expressed by Seweh *et al.* [23] with modification by taking the average of length and diameter of the tuber instead of the diameter alone in the original formula.

$$\% \, Percentage \, Shrinkage = (1 - \frac{X_{2)}}{X_1}) \times 100 \quad (2)$$

where,

X_1 = Initial average length and diameter

X_2 = Final average length and diameter

Collected data were subjected to Analysis of Variance (ANOVA) using generalized linear model of Genstat (Discovering Edition). Means that showed significant difference were separated using Less Significant Differences (LSD) at 0.05% level of probability.

3. Results

3.1 Effect of Environmental Conditions on Physiological Losses of Potato during 12 Weeks Storage

Highest monthly mean temperature was recorded during the month of March, April and May (33, 34 and 31 °C) whereas the lowest monthly mean temperature of 27 °C and 29 °C was observed at the January and February (Table 1). Most part of the storage period was characterized by high monthly mean temperature.

The monthly mean relative humidity was generally very low throughout the storage period as shown in Table 1. Highest value of 49% was observed during the month of May while the lowest value (17%) was recorded at the month of February and March. Generally the relative humidity during the storage was very low.

Data on mean monthly wind velocity showed that highest wind velocity 10.8 kmh^{-1} occurred during the month of May as depicted in Table 1 whilst lowest value of 8.7 km^{-1} was observed during the month of March. However, the overall wind velocity during the study was on the high side.

Table 1. Meteorological Data of Mubi, Adamawa State Nigeria for the Year 2020

Month	Average Temperature (°C)	Relative Humidity (%)	Average Wind Speed (kmh^{-1})
January	27	22	9.5
February	29	17	8.9
March	33	17	8.7
April	34	28	10
May	31	49	10.8

Source: field data 2020 and Worldweatheronline.com

3.2 Effect of Curing Period on Percentage Physiological Weight Loss of Potato during Storage

Table 2 showed the impact of curing periods on the percentage physiological weight loss of potatoes after 12 weeks of storage. Curing periods had no significant ($P > 0.05$) effect on percentage physiological weight loss of potato tubers throughout the 12 weeks of storage. Highest weight loss was observed on potato tuber that were not cured had the highest storage weight loss of 14.90% then followed by three days curing (14.80%) whereas the least value of 7.00% was obtained on tubers cured for seven days.

At 4 Weeks After Storage (WAS), potatoes cured for zero days had the highest weight loss (28.0%) followed by those cured for seven days (22.0%) while the least (12.8%) was noticed on tubers cured for five days. Similar trend was observed at 6 WAS with almost same values of 28.6% for highest weight loss, with 22.0% taking second position and a least value of 12.9%.

Zero curing period still provides the highest percentage weight loss at 8 WAS with 41.4% but seconded by three days curing period (35.6%) and least value still originated from five days curing period (25.0%). In contrast, at both 10 WAS and 12 WAS tubers cured for seven days supplied the highest values with 66.6% and 64.7% weight loss respectively and were both followed by zero days curing period with an equal value of 51.7% each but least value of 33.3% and 31.6% respectively were gotten from tubers cured for five days.

3.3 Effect of Storage Method on Percentage Physiological Weight Loss of Potato during Storage

In terms of storage method, similar trend of non-significant (P> 0.05) effect of the treatment on percentage physiological weight loss of potato tubers continued as revealed in Table 2. Even though, potatoes stored in heap had the highest level of weight loss of 14.60% at 2 WAS but subsequently overtaken by those kept on the floor at 4 (22.3%) and 6 WAS (22.6%) but finally the lead position was reverted back to tubers stored in heap at 8 WAS, 10 WAS and 12 WAS with the percentage physiological weight loss values of 33.8%, 65.3% and 64.0% respectively. The potatoes with highest percentage weight losses was followed by those stored on floor at 2 WAS and 8 WAS (11.6% and 33.6% respectively) then those stored in shaded pit at 4 WAS, 6 WAS, 10 WAS and 12 WAS (19.4%, 19.4%, 41.8% and 40.4% correspondingly). Lowest weight loss values was posted by tubers kept in shaded pit storage at 2 WAS (9.5%), heap storage at 4 (18.5%), 6 (18.5%) and 8 (29.8%) WAS; and finally by floor storage at 10 (38.3%) and 12 (38.3%) WAS.

Table 2. Effect of Curing Period, Storage Method and ABA Level on Percentage Physiological Weight Loss of Potato in Mubi during Storage during 2020 Dry Season Dry Season.

Storage Period	2 WAS	4 WAS	6 WAS	8 WAS	10 WAS	12 WAS
Treatment						
CRP (Days)						
0	14.90a	28.0a	28.6a	41.4a	51.7a	51.7a
3	14.80a	17.3a	17.3a	35.6a	42.4a	42.4a
5	10.90a	12.8a	12.9a	25.0a	33.3a	31.6a
7	7.00a	22.0a	22.0a	27.5a	66.6a	64.7a
P of F	0.771	0.157	0.146	0.682	0.476	0.440
S.E (±)	8.56	5.83	5.88	14.69	20.69	19.46
STM						
Floor	11.60a	22.3a	22.6a	33.6a	38.3a	38.3a
Heap	14.60a	18.5a	18.5a	33.8a	65.3a	64.0a
Pit	9.50a	19.4a	19.4a	29.8a	41.8a	40.4a
P of F	0.753	0.878	0.851	0.688	0.364	0.42
S.E (±)	6.70	7.69	7.62	5.14	19.97	20.53
ABA (ppm)						
0	12.10a	16.2a	16.4a	18.2b	31.1b	29.8b
2	14.70a	25.8a	26.0a	48.9a	73.4a	73.4a
4	8.90a	18.1a	18.1a	30.0b	40.9b	39.5ab
P of F	0.609	0.400	0.393	**0.002**	**0.050**	**0.050**
S.E (±)	5.76	7.46	7.45	8.21	18.51	18.55
Interactions						
CRP×STC	NS	NS	NS	**	NS	NS
CRP×ABA	NS	NS	NS	NS	NS	NS
STC×ABA	NS	*	*	NS	NS	NS
CRP×STC×ABA	NS	NS	NS	*	NS	NS

Means with the same letter are not significantly different *= Significant, **= Highly Significant, WAS= Weeks After Storage, CRP= Curing Period, STM= Storage Method, ABA= Abscisic Acid

3.4 Effect of ABA Levels on Percentage Physiological Weight Loss of Potato during Storage

In the case of the effect of ABA rates on percentage storage weight loss, it had a highly ($P \leq 0.01$) significant influence on the percentage physiological weight loss of potato tubers kept in storage at 8 WAS as demonstrated in Table 2. Similarly, significant ($P \leq 0.05$) effect was revealed at both 10 WAS and 12 WAS. Throughout the 12 weeks of storage, tubers treated with 2 ppm ABA solution showed the highest level (14.70%, 25.8%, 26.0%, 48.9%, 73.4% and 73.4% in that other) of percentage weight loss.

The above quoted means were closely followed by means of tubers treated with 4 ppm ABA level at all (18.1%, 18.1%, 30.0%, 40.9% and 39.5% correspondingly) at all the sampling stages excluding 2 WAS where the application of 0 ppm elicited the second highest (12.10%) percentage weight loss. Conversely, lowest values were obtained on tubers treated with 4 ppm at 2 WAS (9.50%) and those treated with 0 ppm at the subsequent periods of 4 WAS, 6 WAS, 8 WAS, 10 WAS and 12 WAS (16.2%, 16.4%, 18.2%, 31.1% and 29.8% respectively).

3.5 Interaction between Storage Method and ABA Level on Percentage Physiological Weight Loss at 4 WAS

There was a significant ($P \geq 0.05$) interaction between storage method and ABA level at 4 WAS as presented in Table 3. Tubers treated with 0 ppm ABA and stored in heap had the highest percentage weight loss (59.5%) and the lowest (24.5%) was found on those stored in shaded pit. However, when ABA rate was increased to 2 ppm and 4 ppm, tubers kept on the floor recorded the highest values (62.2% and 42.2% respectively) with the lowest values presented by those stored in shaded pit at 2 ppm (35.7%) and heap at 4 ppm (31.0%).

Table 3. Interaction between Storage Method and ABA level on Percentage Physiological Weight Loss of potato at Four Weeks after Storage

ABA Levels (ppm)	0	2	4
Storage Condition			
Floor	50.4	62.2	42.4
Heap	59.5	36.8	31.0
Pit	24.5	35.7	39.6
P of F		0.033	
S.E (±)		13.05	

3.6 Interaction between Storage Method and ABA Level on Percentage Physiological Weight Loss at 6 WAS

A significant ($P \geq 0.05$) interaction was observed between storage method and ABA level at 6 WAS (Table 4). The tubers treated with 0 ppm ABA and stored on floor displayed the greatest value of 30.0% weight loss with those stored in shaded pit displaying the least value of 6.2%. However, when the ABA rate rose to 2 ppm, tubers stored in shaded pit had the greatest percentage weight loss of 44.1% and those stored on floor displaying the least value of 13.3%. A subsequent raised in ABA to 4 ppm, tubers stored on the floor demonstrated the greatest values 24.6% while those stored in shaded pit displayed the least value of 7.8%.

Table 4. Interaction between Storage Method and ABA level on Percentage Physiological Weight Loss of potato at Six Weeks after Storage

ABA Levels (ppm)	0	2	4
Storage Condition			
Floor	30.0	13.3	24.6
Heap	13.0	20.7	21.8
Pit	6.2	44.1	7.8
P of F		0.034	
S.E (±)		13.00	

3.7 Interaction between Curing Period and Storage Method on Percentage Physiological Weight Loss at 8 WAS

Curing period and storage method expressed a highly significant ($P \geq 0.01$) interaction at 8 WAS as shown in Table 5. At floor storage method potatoes cured for three days showed the highest weight loss of 58.5% whereas the lowest value is on those cured for seven (16.3%). Once storage method was changed to heap storage, potatoes cured for zero days took the lead with a mean of 60.5% whilst lowest mean (17.1%) was gotten from those tubers cured for five days. Similarly, when storage method was swapped to shaded pit method, potatoes cured for both five and seven days exhibited the highest mean of 38.1% each and those cured for three days posted the lowest mean (18.9%).

Table 5. Interaction between Curing Period and Storage Method on Percentage Physiological Weight Loss of potato at Eight Weeks after Storage

Storage Condition	Floor	Heap	Pit
Curing Periods (Days)			
0	39.6	60.5	24.0
3	58.5	29.4	18.9
5	19.8	17.1	38.1
7	16.3	28.1	38.1
P of F		0.002	
S.E (±)		16.92	

3.8 Interaction between Curing Period, Storage Method and ABA Level on Percentage Physiological Weight Loss at 8 WAS

A significant ($P \leq 0.05$) interaction was demonstrated between curing period, storage method and ABA rate on the percentage physiological weight loss of potato tubers at 8 WAS as illustrated in Table 6. At 0 ppm of ABA, potato tubers subjected to three days curing period and stored on floor indicated topmost figure (68.7%) with bottommost figure was realized on potato tubers cured for five days and stored in heap (4.4%).

As ABA rate was augmented to 2 ppm similar trend manifested with topmost figure still coming from potato tubers cured for zero days and stored in heap. But on the reverse side, bottommost figure emanates from potato tubers cured for seven days and stored on the floor (4.0%). Furthermore, when ABA rate was amplified to 4 ppm, potato tubers cured for zero days and stored on the floor depicted the topmost figure (68.7%) and the bottommost figure (6.8%) originated from potato tubers cured for three days and stored on the floor.

3.9 Effect of Curing Periods on Percentage Physiological Shriveling Loss of Potato during Storage

No significant ($P > 0.05$) influence was manifested by curing periods on the percentage storage shriveling loss of potato tubers throughout the experimental period (Table 7). Even with that, at 2 WAS sampling period, tubers treated with seven days curing period had the maximum shriveling loss of 66.2% while potato tuber treated with zero curing days expressed the minimum levels of percentage shriveling loss from 4 WAS to 12 WAS sampling periods (15.4%, 26.4%, and 26.6%, 42.3% and 51.6% respectively).

Table 6. Interaction between Curing Period, Storage Method and ABA level on Percentage Physiological Weight Loss of potato at Eight Weeks after Storage

Curing Periods	Storage Conditions	ABA Levels		
		0	2	4
0	Floor	39.7	10.5	68.7
	Heap	38.4	100.0	43.2
	Pit	11.6	18.3	42.2
3	Floor	68.7	100.0	6.8
	Heap	8.4	68.1	11.8
	Pit	8.6	38.4	9.8
5	Floor	11.8	37.1	10.6
	Heap	4.4	37.1	9.9
	Pit	7.8	36.7	69.9
7	Floor	5.6	4.0	39.3
	Heap	6.5	37.2	40.7
	Pit	7.0	100.0	7.4
P of F			0.040	
S.E (±)			28.73	

Second in terms of percentage physiological shriveling loss are potato tubers cured for three days at 2 WAS, 4 WAS, 10 WAS and 12 WAS sampling period (52.1%, 12.8%, 35.2% and 44.2% in that order). Similarly potato tubers cured for seven days at 6 and 8WAS sampling periods (19.0% and 23.3% correspondingly). Minimum levels were however exhibited by potatoes treated with five days curing period from 2 WAS to 12 WAS (38.2%, 9.3%, 11.7%, 11.8%, 25.5% and 29.4% respectively).

3.10 Effect of Storage Method on Percentage Physiological Shriveling Loss of Potato during Storage

Storage method displayed no significant (P > 0.05) effect on percentage shriveling loss during storage of potato tubers at all the observation points (Table 7). In face of that, potato tubers stored in heap gave the greatest percentage shriveling losses at 2 WAS, 4 WAS and 10 WAS with values of 70.1%, 14.6% and 33.7% respectively. Likewise at 6 WAS and 8 WAS, greatest values of 20.3% and 20.9% accordingly were gotten from potato tubers stored on floor. Finally, at 12 WAS potato tubers stored in shaded pit gave the greatest value of 41.8%.

Greater percentage storage shriveling losses of 47.0%, 12.0% and 33.4% were produced by potato tubers stored on floor at 2 WAS, 4 WAS and 10 WAS in that order. In the same vein, greater losses of 19.0% and 18.6% were observed on potato tubers stored in shaded pit at 6 WAS and 8 WAS respectively. So also potato tubers stored in heap recorded greater loss of 41.2% at 12 WAS sampling period.

Potato tubers stored in shaded pit posted least percentage storage shriveling losses of 45.2%, 8.6%, and 31.7 % at 2 WAS, 4 WAS and 10 WAS sampling periods correspondingly. So also, least losses of 17.1% and 17.4% were sent in by potato tubers stored in heap at 6 WAS and 8 WAS respectively. In the same way, potato tubers stored on floor forwarded a least loss of 39.7% at 12 WAS sampling time.

Table 7. Effect of Curing Periods, Storage Method and ABA Levels on Percentage Physiological Shrinkage Loss of Potato in Mubi during Storage during 2020 Dry Season.

Storage Period	2 WAS	4 WAS	6 WAS	8 WAS	10 WAS	12 WAS
Treatment						
CRP (Days)						
0	59.8a	15.5a	26.4a	26.6a	42.3a	51.6a
3	52.1a	12.8a	14.0a	14.2a	35.2a	44.2ba
5	38.2a	9.3a	11.7a	11.8a	25.5a	29.4b
7	66.2a	9.3a	19.0a	23.3a	28.7a	38.4ba
P of F	0.483	0.825	0.088	0.112	0.665	0.399
S.E (±)	17.74	7.70	5.27	5.72	14.19	12.29
STM						
Floor	47.0a	12.0a	20.3a	20.9a	33.4a	39.7a
Heap	70.1a	14.6a	17.1a	17.4a	33.7a	41.2a
Pit	45.2a	8.6a	19.0a	18.6a	31.7a	41.8a
P of F	0.408	0.665	0.914	0.895	0.928	0.961
S.E (±)	20.17	6.51	7.61	7.47	5.61	7.93
ABA (ppm)						
0	34.1b	10.3a	15.5a	15.4a	18.9b	29.0b
2	83.5a	15.5a	25.3a	25.7a	50.4a	54.1a
4	44.5b	9.4a	15.5a	15.8a	8.60b	39.6ba
P of F	**0.028**	0.590	0.342	0.307	**0.002**	**0.017**
S.E (±)	18.73	6.41	7.62	7.50	17.31	8.50
Interactions						
CRP×STC	NS	NS	NS	NS	**	NS
CRP×ABA	NS	NS	NS	NS	NS	*
STC×ABA	NS	NS	*	*	NS	*
CRP×STC×ABA	NS	NS	NS	NS	NS	NS

Means with the same letter are not significantly different *= Significant, **= Highly Significant, WAS= Weeks After Storage, CRP= Curing Period, STM= Storage Method, ABA= Abscisic Acid

3.11 Effect of ABA Levels on Percentage Physiological Shriveling Loss of Potato during Storage

Different rate of ABA expressed significant ($P \leq 0.05$) impression on percentage physiological shriveling loss of potato tubers at both 2 WAS and 12 WAS (Table 7). It equally expressed a highly significant ($P \leq 0.01$) impression at 10 WAS on potato tubers during storage as also shown in Table 7.

Nevertheless, potato samples subjected to the treatment of 2 ppm ABA concentration presented the greatest percentage physiological shriveling losses (83.5%, 15.5%, 25.3%, 25.7%, 50.4% and 54.1% respectively) in the 12 weeks experimental periods.

Potato samples subjected to the treatment of 4 ppm offered greater percentage storage shriveling losses (44.5%, 15.5%, 15.8%, 29.4% and 39.6%) at all the sampling stages of 2 WAS, 6 WAS, 8 WAS, 10 WAS and 12 WAS respectively apart from 4 WAS sampling period that handed out greater loss on samples treated with 0 ppm of ABA level.

Conversely, samples subjected to 0ppm of ABA treatment presented the least percentage storage shriveling losses (34.1%, 15.5%, 15.4%, 18.9% and 20.0%) in all the sampling periods with the exclusion of 4 WAS (9.4%) where samples subjected to 4 ppm of ABA presented the least loss.

3.12 Interaction between Storage Method and ABA Levels on Percentage Physiological Shriveling Loss at 6 WAS

A significant ($P \leq 0.05$) interaction was witnessed between storage method and ABA level at 6 WAS (Table 8). The potatoes treated with 0 ppm ABA and stored on floor revealed the uppermost value of 28.7% storage shriveling loss while the lowermost value was on potatoes stored in shaded pit. Once the ABA rate was raised to 2 ppm, potatoes stored in shaded pit had the uppermost value of 43.5% with lowermost value coming from potatoes stored on the floor. However, when the ABA rate was redoubled to 4 ppm, potatoes stored on floor revealed the uppermost values 19.7% whereas the lowest value stem from potatoes stored in shaded pit.

3.13 Interaction between Storage Method and ABA Level on Percentage Physiological Shriveling Loss at 8 WAS

A significant ($P \leq 0.05$) interaction was demonstrated between storage method and ABA rate on the percentage physiological shriveling loss of potato tubers at 8 WAS as illustrated in Table 9. Potato tubers sprayed with a mist of 0 ppm ABA and stored on the floor recorded the highest shriveling loss of 29.6% and the lowest value of 4.4% arising from potato tubers stored in shaded pit. However upon increasing the rate of ABA to 2 ppm potato tubers stored in shaded pit recorded the highest shriveling loss of 43.6% with the lowest value of 13.4% springing from potato tubers stored on floor. As ABA rate was further enhanced to 4 ppm potato tubers stored in heap gave the highest value of 20.0% whilst the lowest value of 7.8% was gotten from shaded pit storage method.

Table 8. Interaction between Storage Method and ABA levels on Percentage Physiological Shriveling Loss of potato at Six Weeks after Storage

ABA Levels (ppm)	0	2	4
Storage Condition			
Floor	28.7	12.4	19.7
Heap	11.6	19.9	19.4
Pit	6.0	43.5	7.4
P of F		0.051	
S.E (±)		13.19	

Table 9. Interaction between Storage Method and ABA levels on Percentage Physiological Shriveling e Loss of potato at Eight Weeks after Storage

ABA Levels (ppm)	0	2	4
Storage Condition			
Floor	29.6	13.4	19.7
Heap	12.2	20.1	20.0
Pit	4.4	43.6	7.8
P of F		0.041	
S.E (±)		12.98	

3.14 Interaction between Curing Periods and Storage Method on Percentage Physiological Shriveling Loss of Potato at 10 Weeks After Storage

Interaction between curing periods and storage method was highly ($P \leq 0.01$) significant at 10 WAS as depicted in Table 10. Samples cured for three days and placed on floor posted the greatest mean (58.3%) while the least mean (17.0%) was obtained on samples cured for seven days. When storage condition was changed to heap method, samples cured for zero days took the lead with 59.3% physiological shriveling loss although least mean (19.0%) was observed on samples cured for five days. Samples cured for seven days had the greatest value (40.8%) after subsequently placing the samples in shaded pit, least mean (19.1%) was declared by samples cured for three days.

Table 10. Interaction between Curing Periods and Storage Method on Percentage Physiological Shriveling Loss of potato at Ten Weeks after Storage

Storage Condition	Floor	Heap	Pit
Curing Periods (Days)			
0	39.8	59.3	27.9
3	58.3	28.3	19.1
5	18.6	19.0	39.0
7	17.0	28.2	40.8
P of F		0.005	
S.E (±)		16.89	

3.15 Interaction between Curing Period and ABA Level on Percentage Physiological Shriveling Loss of Potato at 12 Weeks After Storage

The interaction between curing periods and ABA rates at 12 WAS was significant ($P \leq 0.05$) as presented in Table 11. Potato tubers treated with three days curing period and 0 ppm ABA gave the highest shriveling loss of 41.9% while tubers cured for seven days and the same amount of ABA disclosed the lowest loss of 11.2%. In the same vein, when the ABA level was increased to 2 ppm potato tubers treated with three days curing period still maintain the lead with a shriveling loss of 79.6% but the lowest loss of 35.5% occurred on tubers cured for five days. After redoubling ABA rate to 4 ppm, tubers treated with zero curing period revealed the highest storage shriveling loss of 62.0% as the lowest loss occurred on potato tubers cured for three days.

Table 11. Interaction between Curing Period and ABA Level on Percentage Storage Shriveling Loss of Potato at Twelve Weeks of After Storage

Abscisic Acids Levels (ppm)	0	2	4
Curing Periods (Days)			
0	41.6	51.1	62.0
3	41.9	79.6	11.2
5	21.4	35.5	31.4
7	11.2	50.4	53.8
P of F		0.017	
S.E (±)		18.54	

3.16 Interaction between Storage Method and ABA Level on Percentage Physiological Shriveling Loss at 12 WAS

A significant ($P \leq 0.05$) interactive effect was noticed between storage method and ABA rate on the percentage physiological shriveling loss of potato tubers at 12 WAS as exemplified in Table 12. Potato tubers treated with 0 ppm of ABA and stored up on floor was accorded the topmost value (47.7%) alongside bottommost value (12.7%) emanating from tubers stored in shaded pit. As ABA leveled to 2 ppm, potato tubers stored in heap and shaded pit scored the topmost shriveling loss (62.4%) and bottommost loss (37.6%). After ABA level was augmented to 4 ppm, potato tubers stored in shaded pit displayed topmost value (50.4%) and bottommost value (33.6%) was realized from potato tubers stored on floor.

Table 12. Interaction between Storage Method and ABA level on Percentage Storage Shriveling Loss of potato at Twelve Weeks after Storage

ABA Levels (ppm)	0	2	4
Storage Condition			
Floor	47.7	37.6	33.6
Heap	26.6	62.4	34.8
Pit	12.7	62.4	50.4
P of F		0.038	
S.E (±)		14.40	

4. Discussions

4.1 Effect of Environmental Conditions on Physiological Losses of Potato during 12 Weeks Storage

The high monthly mean temperature that characterized most part of the storage period was disastrous to storage because it leads to increase in rate of respiration and transpiration that subsequently depleted moisture which results in weight loss and shriveling. This result is in tandem with Baerdemaeker *et al.* [8] who acknowledged that physiological rates of harvested produce is strongly influenced by temperature, an increased in temperature caused increased metabolic reaction rates. Voss *et al.* [11] also stated that high temperature is responsible for increased respiration that could lead to weight loss. Similarly, high postharvest temperature was found to have a negative effect on potato tuber's physiological quality due to elevated respiration caused by high temperature which diminishes both water and carbohydrate content of the tuber [24]. Abubakar *et al.* [25] further reported similar findings on onion bulbs storage.

Very low monthly mean relative humidity was observed throughout the storage period which encourages water vapour loss due to vapour pressure difference in favour of the environment that caused moisture to migrate from the tubers to the surrounding environment. Voss *et al.* [11] recorded similar observation that low humidity below

90% caused rapid weight loss in potato tubers during storage. In the same vein, Abubakar *et al.* [25] documented that high relative humidity caused swelling of onion bulbs due to moisture absorption while low humidity leads to moisture exhaustion.

The mean monthly wind velocity of the storage environment was high which promoted rapid transpiration evaporation of moisture from the potato tubers to the surrounding that ensued in weight loss and shrinkage of the produce. High wind velocity caused physiological quality loss through transpiration and evaporation of moisture from the tissue and surface of the produce. This is in conformity with De Baerdemaeker *et al.* [8] who found that high wind velocity caused rapid moisture loss in root crops. Abubakar *et al.* [25] also affirmed that high wind velocity influences moisture loss in onion bulbs during storage.

4.2 Effect of Curing Period on Physiological Weight Loss of Potato during Storage

Physiological weight loss is a direct indicator of quality deterioration and financial loss since it translates into overall weight loss of the produce through moisture depletion. There was no significant difference between various curing periods on percentage physiological weight loss of potato tubers throughout the 12 weeks of storage which may be due to environmental conditions. However, curing potato tubers for five days provided the lowest percentage physiological weight loss throughout the 12 weeks of storage with the exception of 2 WAS. This could be attributed to effective suberisation of the periderm or wound healing that help to reduce water loss and subsequent weight loss. The finding of this study is in line with Jayanty, Thompson, Potatoes USA and FAO who recommended a curing period of 3 to 5 days or 5 to 10 days respectively [26-29]. As a guide to curing period, Holcroft [30] suggested that the higher the temperature, the lower the curing period.

4.3 Effect of Storage Method on Physiological Losses of Potato during Storage

In terms of storage method, non-significant effect of the treatment on percentage physiological weight loss of potato tubers was revealed throughout the storage period. Nevertheless, lowest weight loss values were posted by shaded pit storage at 2 WAS and 8 WAS, heap storage at 4 WAS and 6 WAS; and finally by floor storage at 10 WAS and 12 WAS. The in consistency in weight loss reported under different storage conditions may be due to high ambient temperature, low relative humidity and high wind speed that were prevalent in the storage environment during most part of the storage period (January-May) which in turn affected the rate of respiration, transpiration and evaporation. Transpiration and evaporation in root crops is a mass transfer process in which moisture is lost from the produce to the environment. Other researchers like Baerdemaeker *et al.* [8], Dandago and Gungula [34], Sugri *et al.* [35], Ezeocha and Ironkwe [36] all asserted that storage conditions and environmental factors like temperature and relative humidity affect the physiological quality of different types of potatoes during storage.

4.4 Effect of Abscisic Acid Level on Physiological Weight Losses of Potato during Storage

In the case of the effect of ABA on percentage storage weight loss, a highly significant impact on the percentage weight loss of potato tubers kept in storage manifested at 8 WAS. Throughout the 12 weeks of storage, lowest values were obtained on tubers treated with 0 ppm excluding 2 WAS. The reduction in percentage physiological weight loss caused by ABA application revealed in this experiment could be due the adverse environmental effect coupled with ABA. This result is contrary to the findings of recent studies that showed that ABA help to reduce water vapour loss in injured potato tubers in storage [26,17,38] and thus causing less physiological losses such as percentage physiological weight loss. The non-influence of the treatment weight loss on the tuber at most periods could be ascribed to declining effect of ABA which leads to high rate of respiration and transpiration. This suggested that application of ABA had assisted in minimizing weight loss at the beginning but the effect declined as storage time progress. This outcome is in total agreement with Lulai *et al.* [12] and Alamar *et al.* [17] who opined that ABA help in controlling weight loss through reducing respiration and transpiration of the tubers in storage but require repeated application for long lasting effect.

4.5 Interaction between Curing Period and Storage Method on Percentage Physiological Weight Loss of Potato Tubers at 8 Weeks After Storage

Curing period and storage method showed a highly significant interaction at 8 WAS where potatoes cured for seven days and stored on floor had the least percentage storage weight loss. The interaction effect could be due to the combined effect of curing period and storage method which in turn encourages extension of shelf-life and postharvest quality as earlier disclosed by other researchers Jayanty [26], Dandago and Gungula [34], Agbemafle *et al.* [41], Mustafa *et al.* [42], Sugri *et al.* [35], Teme *et al.* [43] who found that curing and storage environment assist in long term storage of different types of potatoes.

4.6 Interaction between Storage Method and ABA Level on Percentage Physiological Weight Loss of Potato Tubers at 4 Weeks After Storage

There was a significant interaction existing between storage method and ABA level at 4WAS. This could be due to the dual effects of storage method and ABA level on the percentage physiological weight loss of the tubers. This result is similar to Jayanty [26], Hassan *et al.* [44], Gherghina *et al.* [45] who reported that ABA, curing and storage method affect the quality of both ordinary and sweet potatoes in storage.

4.7 Interaction between Storage Method and ABA Level on Percentage Physiological Weight Loss of Potato Tubers at 6 Weeks After Storage

Significant combination effect manifested between storage method and ABA level at 6 WAS. This could be attributable to the joint influence of storage method and ABA level on this physiological quality attributes of potatoes. This disclosure is similar to Hassan *et al.* [44], Gherghina *et al.* [45] who reported an interplay between ABA, curing and storage method on the quality of both ordinary and sweet potato respectively.

4.8 Interaction between Curing Period, Storage Method and ABA Level on Percentage Physiological Weight Loss of Potato Tubers at 8 Weeks After Storage

A significant interaction was demonstrated between curing period, storage method and ABA rate on the percentage physiological weight loss of potato tubers at 8 WAS which could be as a result of the combination of three factors on percentage physiological weight loss as reported earlier by Hassan *et al.* [44].

4.9 Effect of Curing Period on Physiological Shriveling Losses of Potato during Storage

Shriveling is a sign of severe water loss in a produce and an important mark of quality in potato storage. No significant variation manifested by different curing periods on the percentage storage shriveling loss of potato tubers throughout the experimental period. Despite that, five days curing period furnished the lowest percentage shriveling loss from 2 WAS to 12 WAS. This is cannot be unconnected with proper wound healing of the periderm or suberisation that check water loss which directly related to tuber shriveling. This position is the same with that of Jayanty [26], Krochmal-Marczak *et al.* [31], Wang Y *et al.* [32], Olsen and Miller [33] who also postulated that curing periods significantly help in reducing shriveling loss during potato tuber storage.

4.10 Effect of Storage Method on Physiological Shriveling Losses of Potato during Storage

Storage conditions indicated no significant changes in percentage shriveling loss in potato tubers. Nonetheless, storage of potatoes in shaded pit posted least percentage storage shriveling losses at 2 WAS, 4 WAS and 10 WAS sampling periods. So also, least losses were sent in by potato tubers stored in heap at 6 WAS and 8 WAS respectively. In the same way, potato tubers stored on floor forwarded a least loss at 12 WAS sampling time only. This phenomenon can be associated with the cool temperature and high relative humidity provided by both shaded pit and heap storage methods. The outcome of this study is in agreement with the findings of Ohrvik *et al.* [37], Dandago and Gungula [34], Alamar *et al.* [17], Ezeocha and Ironkwe [36] who said that physiological shriveling is also influenced by storage conditions.

4.11 Effect of ABA Level on Physiological Shriveling Losses of Potato during Storage

Different rates of ABA levels significantly affected percentage storage shriveling loss of potato tubers at both 2 WAS and 12 WAS, it equally expressed a highly significant effect at 10 WAS. Samples subjected to 0 ppm of ABA treatment presented the least percentage storage shriveling losses in all the experimental periods with the exclusion of 2 WAS where samples subjected to 4 ppm of ABA presented the least loss. This could be due to the fading influence of ABA on rate of respiration and transpiration. Similar result was revealed by Jayanty [26], Lulai *et al.* [12], Mani *et al.* [39], Wang Y *et al.* [32], Wang Z *et al.* [40] who ascertained that ABA reduce water vapour loss in potato tubers in storage and thus causing less physiological losses for instance in both percentage weight and shriveling loss.

4.12 Interaction between Curing Period and Storages Method on Percentage Shriveling Loss of Potato at 10 Weeks After Storage

Interaction between curing period and storage method was highly significant at 10 WAS and this may be attested to the mutual effect of the two factors under consideration. This outcome agreed with the results of earlier workers such as Mustefa *et al.* [42], Sugri *et al.* [35], Teme *et al.* [43], Jiru and Usmane [46] who offered that physiological quality of potato tubers during storage depend on many factors including curing and storage conditions.

4.13 Interaction between Curing Period and ABA Rate on Percentage Storage Shriveling Loss of Potato at 12 Weeks After Storage

The interaction between curing period and ABA rate at 12 WAS is significant. The interface between the two factors could be accountable for this development. This discovery is in tandem with Gherghina *et al.* [45] who reported similar result on the effect of exogenous ABA on some quality attributes of sweet potato.

4.14 Interaction between Storage Method and ABA Rate on Percentage Storage Shriveling Loss at 6 Weeks After Storage

A significant interaction was witnessed between storage method and ABA level at 6 WAS. The cause for such effect could be assigned to the collaborative role of the two factors in question and this assertion is assented to by Wang Z *et al.* [40] who commented that physiological quality of potato tubers during storage depend on many factors including plant hormones and storage conditions.

4.15 Interaction between Storage Method and ABA Rate on Percentage Storage Shriveling Loss at 8 Weeks After Storage

A significant interaction was demonstrated between storage method and ABA rate on the percentage storage shriveling loss of potato tubers at 8 WAS. This can be ascribed to the twin influence of ABA rate and storage method as previously mentioned by Wang Z *et al.* [40] on the impact of ABA and storage condition on the quality of sweet potato.

4.16 Interaction between Storage Method and ABA Rate on Percentage Physiological Shriveling Loss at 12 Weeks After Storage

The significant interactive effect that was noticed between storage method and ABA rate on the percentage storage shriveling loss of potato tubers at 12 WAS which could be ascribed to the shared effect of ABA rates and storage method on percentage physiological shriveling loss. This finding was further affirmed by Haider *et al.* [38] and Wang Z *et al.* [40] who found that plant hormones and storage conditions influence the storage of sweet potato.

5. Conclusions

Based on the result of this study, the following conclusions were thus drawn:

Subjecting potato tubers to five days curing period gave the best physiological quality attributes on percentage physiological weight loss and shriveling during storage when compared to other curing periods. Similarly, storing potato tubers in shaded pit provided the best physiological parameters throughout the storage period. However, application of 4ppm ABA levels had a highly significant impact on physiological quality and prevented physiological quality deterioration of potato during storage.

Acknownledgement

I wish to convey my sincere appreciation to Prof. D.T. Gungula and Dr V.T. Tame for their assistance in analyzing the data and review of the work.

Author's Contribution

MA conceived, designed the work, interpreted the data and wrote the manuscript.

Conflict of Interest

The authors declared no conflict of interest.

Funding

This work received no external funding.

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