Acta Univ. Sapientiae, Alimentaria, **16** (2023) 1–17

DOI: 10.2478/ausal-2023-0001

Effect of postharvest management on the microbial quality of potato (*Solanum tuberosum* L.) tubers

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Abstract. This experiment was conducted to appraise the role of the curing phytohormone treatment and storage method in the postharvest microbial decay of ware potatoes during storage. The study was designed as a Split-Split-Plot Design (SSPD) in which the curing period was placed in the main plot, and the storage method and the phytohormone were put in subplot and sub-sub-plot respectively. Each treatment was replicated three times to form a 4 × 3 × 3 factorial experiment. Each treatment consisted of 20 potato tubers out of which decayed samples were counted for the calculation of percentage rot loss and identification of the causal agent, which was done fortnightly until the end of the storage period of 12 weeks. Temperature, relative humidity, and wind velocity were monitored weekly. All data collected were subjected to analysis of variance (ANOVA) using the GenStat Discovery Edition statistical software package. Means that exhibited significant difference were separated using Duncan's Multiple Range Test (DMTR) at $p = 0.05$ level of significance. The results of the analysis showed that the phytohormone levels had highly significant influence ($p \le 0.01$) on percentage rot loss. Although there was a significant interaction between the curing periods and phytohormone concentration, storage conditions ($p \le 0.05$) were observed throughout the storage period of 2–8 weeks. *Fusarium solani*, *Rhizopus oryzae*, and *Aspergillus niger* were implicated in the rotting of potato tubers.

Keywords and phrases: storage rot loss, potato, *Aspergillus niger*, *Fusarium solani*, *Rhizopus oryzae*

1. Introduction

The short production cycle of potatoes (*Solanum tuberosum* L.) makes it possible to supply food faster than most crops, such as cereals or legumes, during emergencies and famine (*Mustefa et al.*, 2017; *Devaux et al.*, 2020). Furthermore, they yield more calories per hectare and require a relatively lower quantity of water when compared to other crops such as wheat or rice (*Sonnewald & Sonnewald*, 2014; *Thapa & Thapa*, 2019; *Burgos et al.*, 2020). Potato tubers are an excellent staple food due to their high nutritional value, which, in addition to their relatively easy cultivation, makes potato increasingly important as a critical crop to feed an ever-increasing world population (*Lisinska et al.*, 2008; *Pandey et al.*, 2017). According to *Burgos et al.* (2020) and *Devaux et al.* (2020), potato is a very important part of world food security, which could help to alleviate poverty, drive economic development, and sustain rural livelihood.

Quality losses caused by biotic factors, such as microbes, have been estimated at 6.1 billion euros with a serious impact on food security (*Adolf et al.*, 2020). Postharvest loss of horticultural crops is about 40-50% (*Teutsch & Kitinoja*, 2019), which is mostly caused by poor postharvest handling and microbial decay. Globally, postharvest losses have recently become a serious source of concern, which made the United Nations to declare Food Loss and Waste (FLW) as one of the Sustainable Development Goals (SDGs) to reduce FLW by 50% by 2030 so as to feed the ever-growing population of the world (*Teutsch & Kitinoja*, 2019). In addition to that, resource-constrained nations are facing challenges in power availability, accessibility, and affordability to embark on cold chain technology.

Other researchers, such as *Lulai et al.* (2008) or *Olsen & Miller* (n. y.), have previously observed that the curing period assisted significantly the control of microbial decay during storage through wound healing or suberization. *Wang et al.* (2020a) stated that curing healed broken potato skin thereby putting a stop to microbial infection, thus combatting microbial attack during storage. Likewise, *Holcroft* (2018), *Jiru & Usmane* (2021) reported that curing helps in minimizing rotting during storage.

Alamar et al. (2017) opined that poor storage conditions of potato tubers can cause significant losses during their postharvest life. Root and tuber crops are more susceptible to microbial deterioration under certain storage conditions, as observed by *Sugri et al.* (2017), *Teme et al.* (2019), *Wang et al.* (2020b), and *Jiru & Usmane* (2021), who reported that storage conditions have a direct impact on the rotting of potato tubers in storage.

Postharvest exogenous application of ABA on micro tubers was found to aid in the control of postharvest disease of potato tubers during storage, as documented by *Adolf et al.* (2020). Similar findings were reported by *Alamar et al.* (2017), *Chen et al.* (2020), *Wang et al.* (2020b), and *Haider et al.* (2021) – they all noted that ABA plays a significant role in the control of microbial spoilage of potatoes through dormancy induction and maintenance.

There is little information about the influence of phytohormone, storage method, and curing on the microbial loss of potatoes during storage. The minimization of these losses is the aim of this research, which seeks a means of improving potato storage longevity under ambient conditions that would control microbial rotting through the use of curing, abscisic acid (ABA), and storage methods.

2. Materials and methods

The materials and equipment for this research include:

1. Fresh, fully matured dry-season potato tubers (Marabel cv. seeds) were obtained from the National Root Crops Research Institute (Jos, Nigeria), which were harvested early in the morning in Kwaja village (Mubi, Nigeria).
2. Abscisic acid (ABA) with a purity of 95% was purchased from Zhengzhon Panpan Chemical Co. Ltd, China.
3. Thermo-hygrometer HTC-2.
4. Automatic Digital Weather Station, Vantage Pro2 model (Davis Instruments, Hayward, CA, USA).

2.1 Curing periods

The curing of potato tubers involves keeping the tubers underneath a tarpaulin cover under high temperature (35°C) and relative humidity (80%) conditions, in a dry, shaded place without ventilation. The tubers were subjected to the following curing periods:

a. No curing period [control] (P_0)
b. Three days curing period (P_1)
c. Five days curing period (P_2)
d. Seven days curing period (P_3)

2.2 Levels of phytohormone (abscisic acid)

The following amounts of abscisic acid were applied to the experimental samples of the potato tubers:

a. Without treatment [control] c = 0 ppm (A_0)
b. Treatment with concentration of c = 2 ppm (A_1)
c. Treatment with concentration of c = 4 ppm (A_2)

2.3 Storage conditions

The following storage methods were employed for the research:

a. C_0: Floor storage on bare concrete floor (control).

b. C_1: Heap storage between layers of paddy straw.

c. C_2: Shaded pit storage (50 × 50 × 70 cm) with alternate layers of paddy straw under shade.

2.4 Experimental design

The experiment was prepared in a Split-Split-Plot Design (SSPD) with curing applied to the main plot while storage conditions and ABA levels apportioned between the sub-plot and the sub-sub-plot. Treatment was replicated three times (4 × 3 × 3 factorial experiment), and temperature, relative humidity, and wind speed of the storage environment were monitored using both a digital thermo-hygrometer and a digital automatic weather station during the experiment. Each treatment consisted of 20 potato tubers, out of which three were labelled and earmarked for data collection.

2.5 Sampling methods and data collection

Purposeful sampling technique was used in the selection of the decayed samples on which data were generated. Data were taken fortnightly on the percentage of rotting parameters, whilst samples for microbial analysis were collected at the end of the storage period. The following methods were used to collect the data:

a. Determination of storage rot loss percentage (% SRL):

Potato tubers with a visibly decayed surface area were considered as rotted according to *Ezeocha & Ironkwe* (2017). Further, the storage rot losses of tubers (% SRL) was calculated by counting the rotted tubers out of the total tubers in each treatment after each sampling period and expressed in percentage. Storage rot loss (% SRL) was calculated according to the following formula (1), as recommended by *Brar & Rana* (2016) and *Abubakar et al.* (2019):

$$\% \, SRL = \left(1 - \frac{N_r}{N_t}\right) \times 100, \tag{1}$$

where: N_r = number of remaining potato tubers, N_t = total number of potato tubers.

b. Microbiological analysis – characterization and identification of isolates:

The samples were subjected to the method of food examination involving the detection of the number and activity of viable microorganisms to ascertain the presence of decay causal agent. The agent was isolated and identified. Rotten samples were collected from the potato tubers at the end of every sampling period and transferred into Petri dishes containing appropriate solid substrate (agar) media and cultured so that they can be eventually identified visually. The dishes were incubated for 48 hours at 37°C. The interest here is to determine the existence of viable microorganisms (bacteria, viruses, and microfungi) without counting them necessarily; thus only to isolate and identify them as recommended by *Onwuka* (2005) and *Ijah et al.* (2014).

The collected data were subjected to analysis of variance (ANOVA) using the generalized linear model. Means that showed significant differences were separated using less significant differences (LSD) at the confidence level of 95%.

3. Results and discussion

3.1 Effect of experimental parameters (curing period (CRP), storage conditions (STC), and abscisic acid concentration (ABA level)) on potato storage rot loss (SRL) during different storage durations

3.1.1 Effect of experimental parameters on storage rot loss (SRL) during different storage durations

Throughout the sampling periods, no significant effect ($p > 0.05$) was found on potato tubers subjected to varying curing periods with regard to storage rot loss (*Table 1*). This result is in disagreement with *Mehrotra & Aggarwal* (2004), who earlier reported that curing periods affected potato tuber decay and water loss. A similar tendency could be observed concerning the impact of storage conditions on storagse rot loss: there was no significant effect ($p > 0.05$) at all sampling periods, as evident in *Table 1*. This finding was again contrary to *Mehrotra & Aggarwal* (2004) and *Sugri et al.* (2017), who claimed that storage conditions influence the decay of potato tubers during storage and transit.

A highly significant influence ($p \leq 0.001$) of the ABA rate on percentage rot loss was observed only at 8 weeks of storage duration (*Table 1*). The highest rot loss was reported on samples treated with 2 ppm (2.50%), while the lowest rot loss was reported for potato tubers without ABA treatment and also at 4 ppm (0 and 1.11% respectively), but both treatments are statistically alike. This outcome is in accordance with *Mehrotra* & *Aggarwal* (2004), *Haider et al.* (2021), and *Wang et al.* (2020), who confirmed that some plant growth regulators help to control *Fusarium*, *Rhizopus*, and *Aspergillus* rotting during the storage of fruits and vegetables.

Accordingly, potato tubers cured in all curing periods and all ABA levels and stored on the floor experienced almost no rotting throughout the storage periods. Specifically, treated potato tubers with 4 ppm ABA, stored for three days in both heap and shaded pit storage had no rotten tubers at the end of the study, as shown in *Table 1*.

Table 1. Statistical results of the effect of parameters on storage rot loss

Storage period (weeks)	2	4	6	8	10	12
Treatment						
CRP (days)						
0	60.8a	1.11a	1.48a	1.48a	0.00a	0.00a
3	53.2a	1.11a	0.37a	1.85a	0.00a	0.00a
5	33.3a	0.74a	0.00a	1.11a	0.00a	0.00a
7	48.4a	0.37a	1.48a	0.37a	0.00a	0.00a
P of F	0.285	0.815	0.198	0.606	-	-
S.E. (±)	12.96	0.896	0.741	1.101	0.00	0.00
STC						
Floor	45.9a	0.83a	0.83a	1.11a	0.00a	0.00a
Heap	48.9a	1.11a	0.83a	1.39a	0.00a	0.00a
Pit	51.9a	0.56a	0.83a	1.11a	0.00a	0.00a
P of F	0.895	0.693	1.000	0.848	-	-
S.E. (±)	12.69	0.661	0.786	0.556	0.00	0.00
ABA (ppm)						
0	39.2a	0.83a	0.83a	0.00b	0.00a	0.00a
2	57.8a	1.11a	0.83a	2.50a	0.00a	0.00a
4	51.9a	0.56a	0.83a	1.11b	0.00a	0.00a
P of F	0.261	0.704	1.000	**0.003**	-	-
S.E. (±)	11.22	0.661	0.600	0.680	0.00	0.00
Interactions						
CRP × STC	NS	NS	NS	NS	-	-
CRP × ABA	*	NS	NS	*	-	-
STC × ABA	*	NS	*	*	-	-
CRP×STC×ABA	NS	NS	NS	NS	-	-

Notes: Means with the same letter are not significantly different; * significant, ** highly significant.

This finding could be attributable to environmental factors such as low temperature, low relative humidity, and high air speed to which the samples were exposed during storage. This condition inhibited microbial development, as also supported by *Mehrotra* & *Aggarwal* (2004) and *Wang et al.* (2020), who earlier observed that low temperature, relative humidity, and good ventilation influence the development of *Fusarium* storage rot of potato tuber. They further opined that this infection probably occurred already in the field, where the soil is infested. The result of this work is also in alignment with *Mani et al.* (2014) and *Wang et al.* (2020), who confirmed the role of curing and storage environment in the rotting of potato during storage. It is also in line with *Sugri et al.* (2017), who reported that postharvest management affects the decaying of tubers by fungi such as *Aspergillus niger*, *Fusarium oxysporum*, or *Rhizopus stolonifer*.

3.1.2 Influence of the interaction between curing period and ABA level on storage rot loss at two weeks of storage

The mean interaction effect between curing period and ABA level on the percentage storage rot loss of potato tubers during storage was significant ($p \leq 0.05$), as shown in *Figure 1*. The lack of ABA treatment and a three days curing period yielded the highest rot loss of 54.6%, while the lowest rot loss occurred after a seven days curing period (15.5%); however, after adding 2 ppm of ABA, potato tubers cured for three days recorded the greatest loss of 90.8%, whereas tubers cured for five days recorded the smallest loss of 32.9%. Following a successive increase of the ABA level to 4 ppm, both uncured and five days cured tubers presented the highest loss (74.9%), and at the same time tubers cured for three days displayed the smallest loss (14.3%). This could be due to both abiotic and biotic factors such as pathogens and low humidity. This finding is in concordance with *Sugri et al.* (2017) and *Chen et al.* (2020), who observed that curing and ABA influence rotting.

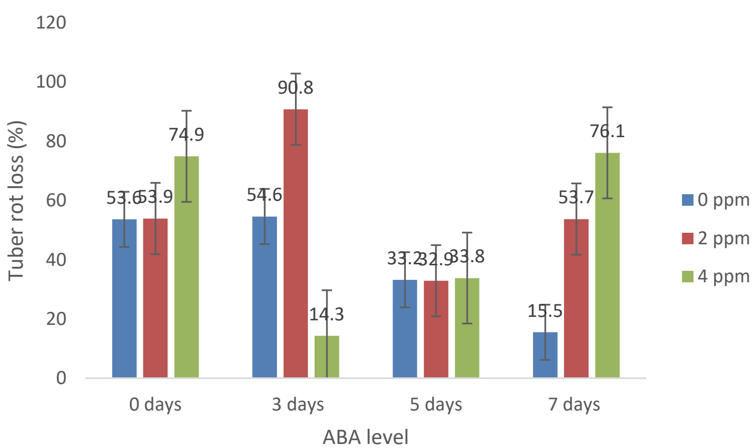

Figure 1. Interaction between curing period and ABA level at two weeks of storage

3.1.3 Interaction between storage conditions and ABA level at two weeks of storage

Storage conditions and ABA levels exhibited a significant ($p \leq 0.05$) interaction at the storage time of 2 weeks, as presented in *Figure 2*. In addition, potatoes stored on the floor had the highest value of 63.6% and the lowest value of 16.7% for shaded pit storage without ABA treatment, and when potatoes were treated with 2 ppm ABA level, potatoes stored in a shaded pit recorded the highest value of 71.7%, and the lowest value was obtained for floor storage, with 37.6%. With a supplementary increase of ABA from 2 ppm to 4 ppm, tubers stored in heap continued to yield the highest rot loss of 67.5%, while the lowest rot loss of 36.6% was observed on potatoes stored on floor. This could be due to the effect of the interplay between storage conditions and ABA on the percentage rot loss, which is in line with *Mani et al.* (2014) and *Wang et al.* (2020b), who reported that storage conditions and ABA treatment affect rotting.

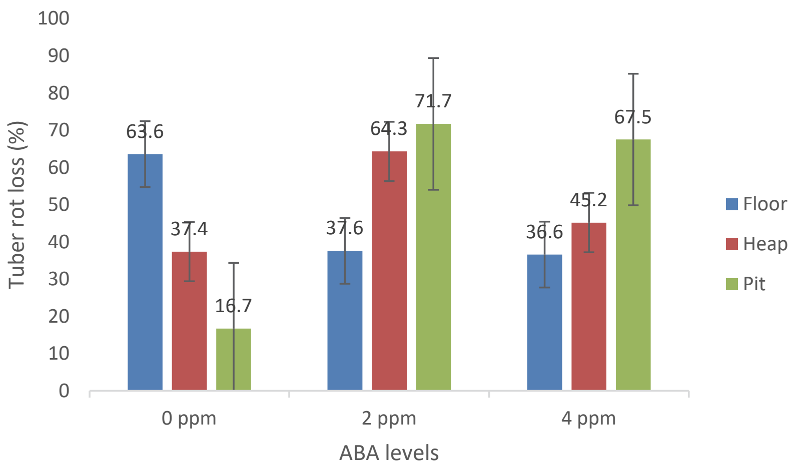

Figure 2. Interaction between storage conditions and ABA level at two weeks of storage

3.1.4 Interaction between storage conditions and ABA levels at six weeks of storage

Storage conditions and ABA levels demonstrated a significant ($p \leq 0.05$) interaction at the storage time of 6 weeks, as shown in *Figure 3*. Similarly, potatoes stored on the floor had the greatest rot loss of 1.67% and the least rot loss of 0.00% on shaded pit storage without ABA treatment (0 ppm), and when ABA was increased to 2 ppm, potatoes stored in shaded pit yielded the greatest value of

2.50%, and the least loss of 0.00% was on potatoes stored on floor and in heap. Following an additional rise of the ABA level to 4 ppm, potatoes stored in heap continually showed the greatest rot loss of 1.67%, and the least of 0.00 % (no rot loss) was spotted on potatoes stored in a shaded pit. This may be attributable to the double effect of storage conditions and ABA on rot loss, which is in tandem with *Mani et al.* (2014) and *Wang et al.* (2020), who reported that storage conditions and ABA impacted microbial spoilage.

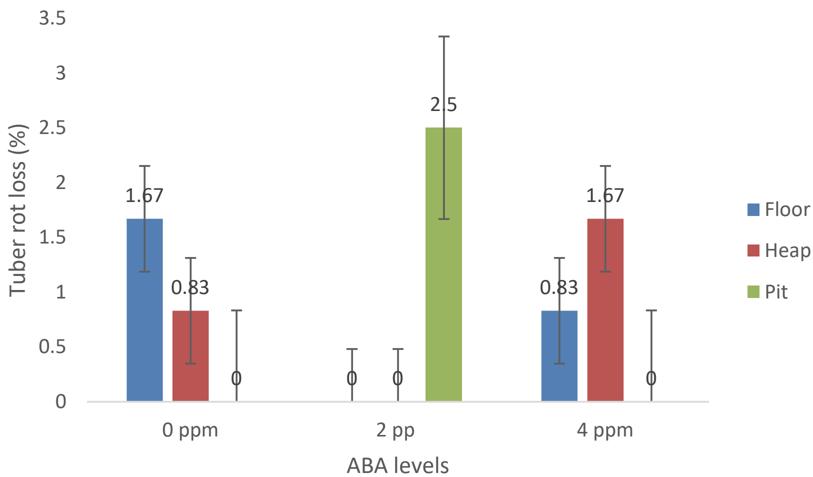

Figure 3. Interaction between storage conditions and ABA level at six weeks of storage

3.1.5 Interaction between curing period and ABA level at eight weeks of storage

The mean interaction effect between curing period and ABA level on the percentage storage rot loss of potato tubers during storage was significant ($p \leq 0.05$), as shown in *Figure 4*. When ABA was not applied, all the curing periods under consideration recorded no rot loss (0.00%), but after adding 2 ppm of ABA, potato tubers cured for three days recorded the highest loss of 5.56%, whilst tubers cured for both five and seven days recorded each the lowest loss of 1.11%. Upon a successive increase of the ABA level to 4 ppm, tubers cured for both zero and five days gave the highest loss of 2.22% each, and at the same time tubers cured for both three and seven days recorded the lowest loss value of 0.00%. This may be owing to the combined influence of curing and ABA on rot loss. This result concurs with *Sugri et al.* (2017) and *Chen et al.* (2020), who observed that curing and plant growth regulators inhibits rotting.

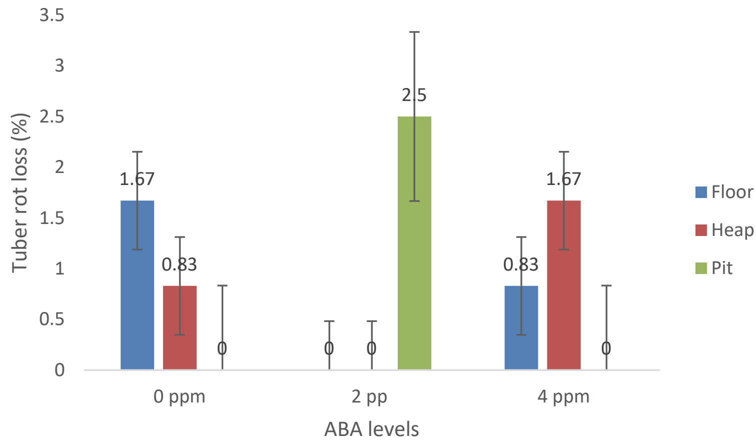

Figure 4. Interaction between curing periods and ABA level at eight weeks of storage

3.1.6 Interaction between storage conditions and ABA level at eight weeks of storage

There was a significant ($p \leq 0.05$) interaction effect of storage conditions and ABA rates at a storage time of 8 weeks on rot loss, as presented in *Figure 5*. In the absence of ABA treatment, no rot loss (0.00%) was recorded regardless of storage conditions; however, adding 2 ppm of ABA led to the highest rot loss (4.17%) of potatoes stored in heap and the smallest (0.83%) loss of those stored in a shaded pit. An additional increase of ABA to 4 ppm triggered potatoes stored in shaded pit to take the lead (2.25% each) in terms of rot loss, while those stored in heap yielded no rot loss (0.00% each). This outcome attests to the impact of the interaction between storage conditions and ABA on the percentage of rot, loss which is concurrent with *Mani et al.* (2014) and *Wang et al.* (2020b), who confirmed that curing and phytohormones play a significant role in the microbial deterioration of potatoes.

Table 2 presented the rotting level of potato tubers subjected to varying curing periods, storage conditions, and ABA levels during 12 weeks of storage under ambient conditions. Bacteria and viruses were not recorded as infectious causal agents for potato rotting during this research. However, fungal attack was noticed as the sole agent responsible for tuber decay on all of the rotten potato tubers.

Despite that, the majority of the samples under study did not record deterioration due to microbial infection. Nonetheless, potato tubers cured for seven days suffered no tuber decay; this was followed by zero days curing with 6 rotten tubers, while the curing periods of three and five days had the highest decay of 9 and 10 tubers respectively. The floor storage method exhibited a minimum deterioration of only

1 tuber followed by shaded pit storage, which had 6 rotten tubers, whereas heap storage conditions recorded the highest number of rotten tubers (18). In the case of ABA treatment, no ABA treatment with 2 ppm ABA concentration had the lowest deterioration (5 tubers), whilst the highest deterioration (13 tubers) was observed on tubers treated with 4 ppm ABA.

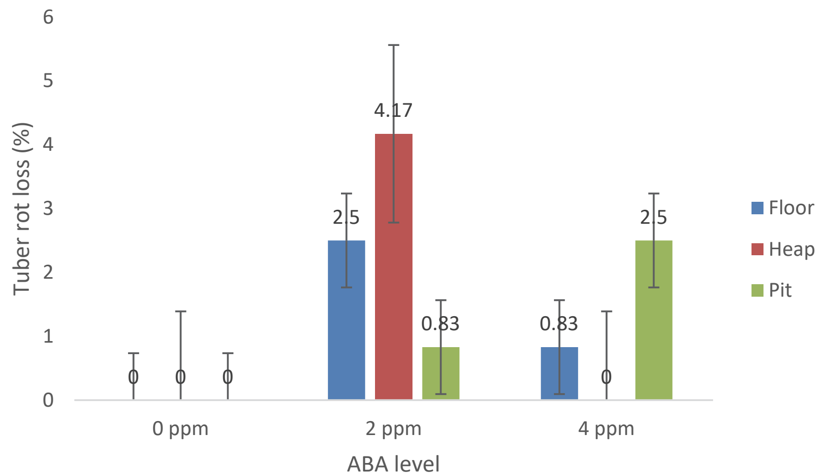

Figure 5. Interaction between storage conditions and ABA level at eight weeks of storage

Three days curing period with heap storage and treated with 2 ppm of ABA level recorded the highest (5 tubers) rotting percentage due to fungal attack at all the sampling periods except at 2 weeks duration of storage time. Next are tubers cured for three days, sprayed with 4 ppm ABA, and stored in heap. Those cured for five days, treated with 4 ppm of ABA, and stored in a shaded pit with 4 tubers each showed infection from 6 to 12 weeks storage time, which was the end of the storage period.

Similarly, samples cured for five days, stored in heap, and untreated with ABA and those cured for five days, stored in heap, and treated with 4 ppm of ABA had 3 tubers decayed in the second half of the storage period (8, 10, and 12 weeks of storage time). Further, uncured potato tubers stored in heap with 2 ppm of ABA experienced fungal spoilage on 2 tubers only in the last two weeks of storage (10 and 12 weeks duration of storage time). Uncured samples with 4 ppm ABA that were stored in a shaded pit all suffered fungal infection on a tuber each in the 12 weeks duration of storage time.

Table 2. The effect of parameters on the rotting level of potato tubers during storage

Treatments								
CRP	STC	ABA	Storage period (weeks)					
(days)		(ppm)	2	4	6	8	10	12
0	Heap	0	-	-	-	-	-	+
3	Heap	0	-	-	-	-	-	-
5	Heap	0	-	-	-	+	+	+
7	Heap	0	-	-	-	-	-	-
0	Heap	2	-	-	-	-	+	+
3	Heap	2	-	+	+	+	+	+
5	Heap	2	-	-	-	-	-	-
7	Heap	2	-	-	-	-	-	-
0	Heap	4	-	-	-	-	-	+
3	Heap	4	-	-	+	+	+	+
5	Heap	4	-	-	-	+	+	+
7	Heap	4	-	-	-	-	-	-
0	Floor	0	-	-	-	-	-	-
3	Floor	0	-	-	-	-	-	-
5	Floor	0	-	-	-	-	-	-
7	Floor	0	-	-	-	-	-	-
0	Floor	2	-	-	-	-	-	+
3	Floor	2	-	-	-	-	-	-
5	Floor	2	-	-	-	-	-	-
7	Floor	2	-	-	-	-	-	-
0	Floor	4	-	-	-	-	-	-
3	Floor	4	-	-	-	-	-	-
5	Floor	4	-	-	-	-	-	-
7	Floor	4	-	-	-	-	-	-
0	Pit	0	-	-	-	-	-	-
3	Pit	0	-	-	-	-	-	-
5	Pit	0	-	-	-	-	-	+

Treatments								
CRP	STC	ABA	Storage period (weeks)					
(days)		(ppm)	2	4	6	8	10	12
7	Pit	0	-	-	-	-	-	-
0	Pit	2	-	-	-	-	-	-
3	Pit	2	-	-	-	-	-	-
5	Pit	2	-	-	-	-	-	-
7	Pit	2	-	-	-	-	-	-
0	Pit	4	-	-	-	-	-	+
3	Pit	4	-	-	-	-	-	-
5	Pit	4	-	-	+	+	+	+
7	Pit	4	-	-	-	-	-	-

In terms of curing period, the five days curing period resulted in the highest decay (11 tubers) across all storage conditions and ABA levels, which was followed by three days curing period with 9 decayed tubers, and seven days curing period recorded no decayed tubers under all storage conditions and across all ABA levels. Similarly, in the case of storage conditions, heap storage led to the highest number of rotten tubers, with 19 tubers affected, followed by pit storage with 6 rotted tubers, while floor storage had the least with only one rotten tuber in all the curing periods and ABA levels.

Tubers treated with 4 ppm ABA experienced the highest rotting (13 tubers). This could be the ABA threshold level that influences rotting, followed by those treated with 2 ppm (8 tubers), and the tubers least infected by fungi under all curing periods and storage conditions were the control tubers (5).

The characterization and identification of fungal isolates were done based on macroscopic and microscopic examination. Three species of fungi were isolated and identified, namely: *Fusarium solani*, *Rhizopus oryzae*, and *Aspergillus niger*. This outcome is similar to *Mehrotra* & *Aggarwal* (2004) and *Ijah et al.* (2014), who identified *Fusarium*, *Rhizopus*, and *Aspergillus* among the major causal agents responsible for causing rot in potato tubers and its products. Similarly, *Sugri et al.* (2017) pointed out that sweet potato was also substantially ravaged by rot-causing pathogens, such as *Aspergillus* and *Fusarium*, during storage. Earlier it was observed that *Fusarium* storage rot of potato tubers occurs in the field, where the high level of inoculum is heavily present in the soil. Similarly, the fungus *Rhizopus oryzae* could be from the rice straw that was used in both heap and shaded pit storage, which may be infested with the pathogen.

4. Conclusions

This study concluded that ABA level at 4 ppm recorded the best rot loss (1.11%), while both curing period and storage conditions with ABA level gave the best results, the highest rot loss at a storage duration time of 8 weeks. The study also identified and characterized *Fusarium solani*, *Rhizopus oryzae*, and *Aspergillus niger* as the major causal agent of the rotting of potato tubers in the study area. Furthermore, potato tubers cured for three days with 4 ppm ABA level and stored in both heap and shaded pit storage had no rotten tubers during the study.

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