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GENOTYPE AND ABSCISIC ACID INTERACTION ON TUBER DORMANCY AND SPROUTING DURING AMBIENT STORAGE IN POTATO

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ABSTRACT: Genotype and abscisic acid (ABA) interaction on tuber dormancy and sprouting were studied in the tubers of eleven potato genotypes during ambient storage. Tubers were harvested and hardened for ten days in the fields. Tuber weights were measured. Tubers were then stored after three treatments: 1) untreated tubers as such; 2) tubers treated with ABA solution, 3) tubers treated with water. During storage, dormancy length was measured. The longest sprout length and sprout numbers were measured at 30, 37, 42, 45, 50 and 60 d after storage. Tuber rottage was measured at 72 d after storage. Results found tubers of Lady Rosetta and Kufri Sindhuri having low tuber weights and longer dormancy duration while lesser sprouting and rottage compared to other genotypes. ABA treatment increased dormancy duration in Lady Rosetta, Kufri Neelkanth, Kufri Frysona, and Kufri Sindhuri. ABA treatment reduced sprouting in Kufri Neelkanth, Kufri Frysona, Kufri Chipsona 1, Kufri Ganga, Lady Rosetta, MP/06 39 and MS/8 1148. ABA treatment decreased rottage in Kufri Pukhraj, Kufri FryoM, Kufri Frysona, MS/8 1148, Kufri Neelkanth, Kufri Chipsona 1 and Kufri Sindhuri. Results indicated that tubers of Lady Rosetta and Kufri Sindhuri could be storable at ambient temperature compared to other genotypes. ABA treatment of tubers may improve tuber storage under ambient conditions in potato.

KEYWORDS: Abscisic acid, dormancy, sprouting, *Solanum tuberosum*

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a non-grain food crop. A major problem in potato management is potato storage after harvest. After harvest, tubers are prone to post harvest damage as these are semi -perishable. In efforts to reduce such damage, tubers are stored in cold stores (Olsen *et al.*, 2009; Campbell *et al.*, 2014; Gupta *et al.*, 2015). In such commercial storages, chemicals like chlorpropham (CIPC) are used to suppress post-harvest sprouting. These efforts increase shelf life of tubers but increase the cost for farmers and raise societal and health concerns regarding the use of chemicals on eatables (Paul *et al.*, 2016). Extension of tuber dormancy in potato cultivars may help to improve shelf-life. Potato tuber dormancy is an inherent trait (Olsen, 2009). To improve storage of potato tubers, longer dormancy can be built in potato cultivars by breeding programs. Few studies have shown that tuber weight can be the best variable related to dormancy length (Claassens and Vreugdenhil, 2000).

Potato tubers undergo three processes during storage, endodormancy, paradormancy and tuber aging. Endodormancy is due to endogenous factors, in which tubers do not sprout even under favorable conditions. Paradormancy is also known as apical dominance in which one leading sprout i.e., apical sprout grows and suppresses lateral sprouts to develop and grow. Tuber aging comes later in which extent of sprouting increases with multi-spouts, and branches

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(Coleman, 2000; Sonnewald and Sonnewald, 2014).

Like seed dormancy, tuber dormancy related to ABA content (Destefano-Beltran *et al.,* 2006a; b; Campbell *et al.,* 2014; Muthoni *et al.,* 2014; Sonnewald and Sonnewald, 2014). Declined level of ABA during storage has been related to loss of dormancy and start of tuber sprouting (Campbell *et al.,* 2014; Muthoni *et al.,* 2014). Nitric oxide treatment of dormant tubers released tuber dormancy and induced sprouting while decreased ABA metabolism and signaling (Wang *et al*., 2020). Therefore, ABA is having role in the maintenance of tuber dormancy during storage. Thus, applying ABA to potato tubers may increase dormancy thus could help in improving shelf life of potato tubers, however, is not well studied.

In the present study, the effect of genotype and ABA interaction has been studied during tuber storage in eleven potato genotypes where tubers were stored under ambient conditions. Four genotypes, Lady Rosetta, Kufri FryoM, Kufri Chipsona-1, Kufri Frysona were the known processing varieties. Lady Rosetta is exotic and red colored variety. Kufri Pukhraj and Kufri Ganga were the table purpose varieties for cultivation. Kufri Neelkanth and Kufri Sindhuri were the varieties developed for purple/red skinned tubers. MS/7 645, MP/06 39 and MS/8 1148 were the genotypes included in the study.

MATERIALS AND METHODS

Plant material

Tubers of potato (*Solanum tuberosum* L.) genotypes (Lady Rosetta, Kufri Pukhraj, Kufri FryoM, Kufri Neelkanth, MS/7 645, Kufri Ganga, Kufri Chipsona-1, Kufri Frysona, MP/06 39, MS/8 1148 and Kufri Sindhuri) were sown in the experimental farm of the Department of Vegetable Science, Punjab Agricultural University, Ludhiana. Tubers were sown on ridges (20 cm tuber to tuber spacing and 60 cm row to row spacing) in plot (4 × 2.4 m^2). Tubers were haulm killed at 90 days after sowing and harvested at 120 days after sowing. Harvested tubers were hardened under field conditions for 10 days then stored. Temperature and humidity measurements during crop growth were obtained from the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana.

For storage, tubers were packed in jute bags and kept in the room. The temperature and humidity of the room during tuber storage were recorded on a daily basis. Tubers stored as such without any treatment were marked as untreated tubers. Tubers sprayed with 10 µM ABA solution were marked as ABA-treated while tubers sprayed with water were marked as water-treated (water control). Spraying was done six times at the interval of 15 minutes, tubers were then dried and stored.

Measurement of tuber dormancy

Dormancy was considered the number of days after storage when 80% of tubers gained longest sprout length more than 2 mm.

Measurement of tuber sprouting

Longest sprout length (LSL) and sprout numbers per tuber were measured at 30. 37, 42, 45, 50 and 60 days after storage (where n=30 tubers).

Measurement of tuber weight

Tuber weight (n=15 tubers) were measured at the time of storage.

Measurement of tuber rottage

The number of tubers rotted out of thirty tubers were measured at 72 days after storage.

Statistical analysis

Data of sprouting were subjected to analysis of variance (ANOVA) followed by estimated marginal means (emmeans) measurements and then emmeans were separated by Fisher's L. S. D. at p Ý 0.05 using R-studio. Box plot for tuber weight was generated using R-studio.

RESULTS AND DISCUSSION

Temperature and humidity variations during crop growth and during tuber storage

During crop growth, temperature decreased from about 24°C at the time of sowing to 12°C around the time of haulm killing then raised to about 15°C around the time of harvest then raised to about 20°C till the time of storage (Fig. 1a). Relative humidity varied from 60 to 95% during crop growth. During storage, temperature and humidity varied from 23-36^{o}C and 40-70% respectively (Fig. 1b).

Tuber dormancy

Three genotypes Kufri Sindhuri, Lady Rosetta and MS/7 645 showed longer dormancy length (Table 1) compared to others. Longer dormancy period for Kufri Sindhuri (>75 days) compared to Kufri Pukhraj, Kufri Chipsona 1 and Kufri Frysona (>45 days) has been reported (Gupta *et al.*, 2015) during ambient storage. ABA treatment increased dormancy length in four genotypes Lady Rosetta, Kufri Neelkanth, Kufri Frysona and Kufri Sindhuri. ABA is reported to be positive for tuber dormancy maintenance (Biemelt *et al.*, 2000; Destefano-Beltran *et al.*, 2006a; b).

Tuber sprouting and tuber rottage

ANOVA results (Table 2) showed significant interactions among genotype (G), treatment (T) and storage duration (D) on longest sprout length (LSL) and sprout numbers.

Table 1: Effect of genotype and ABA on dormancy length in eleven potato genotypes

Genotype	Dormancy length after storage (days)		
	Untreated tubers	Water treated tubers	ABA treated tubers
Lady Rosetta	60	60	70
Kufri Pukhraj	40	40	40
Kufri FryoM	30	30	30
Kufri Neelkanth	35	35	42
MS/7 645	60	60	60
Kufri Ganga	50	50	50
Kufri Chipsona1	40	42	42
Kufri Frysona	35	35	43
MP/06 39	50	50	50
MS/8 1148	40	45	45
Kufri Sindhuri	60	60	>70

†Values are the number of days after storage when 80% of tubers (i.e., 24 tubers out of 30 tubers) showed longest sprout length ≥ 2 mm.
††Tubers were harvested after 30 days of haulm cutting and hardened in fields for 10 days, then treated with water (as control) and 10 μM ABA solution then dried and stored. Untreated tubers stored directly without any treatment.

Table 2: ANOVA result showing effect of genotype (G), treatment (T) and duration of storage (D) and their interaction on longest sprout length and sprout number per tuber

Effect	*Df*	MS	
		longest sprout length tuber^{-1}	sprout number tuber^{-1}
G	10	1613***	64.62***
T	2	19	46.78***
D	5	3578***	263.8***
G: T	20	124***	7.61***
G: D	50	92***	3.71***
T: D	10	53***	6.08***
G: T: D	100	15***	1.18***
Residuals	5742		

†Significant effects at p ≤ 0.001, 0.01 and 0.05 shown as ***, ** and * respectively.

LSL (Table 3) remained low in Kufri Sindhuri, Lady Rosetta and MS/7 645 compared to other genotypes during storage. ABA treatment decreased LSL in Kufri Neelkanth at 42, 45, and 50d compared to

Table 3: Effect of ABA treatment on longest sprout length in tubers of eleven potato genotypes at different days (d) after storage at ambient temperature

Duration	Treatment	Genotypes										
		Lady Rosetta	Kufri Pukhraj	Kufri FryoM	Kufri Neelkanth	MS/7 645	Kufri Ganga	Kufri Chipsona1	Kufri Frysona	MP/06 39	MS/8 1148	Kufri Sindhuri
30 d	UT	0	0.2	2.24	1.24	0.04	0.1	0.64	0.7	0.3	0	0
	WT	0	0.15	2.05	1.5	0.03	0.3	0.65	2.22	0.35	0	0
	ABA	0	0.4	2.37	0.33	0.03	0	0.72	0.65	0.8	0.12	0
37 d	UT	0.12	1.23	3.15	2.55	0.29	0.42	1.14	2.07	0.72	0.47	0
	WT	0.13	2.07	3.52	2.57	0.28	0.93	0.98	4.23	1.1	0	0
	ABA	0.03	1.65	3.97	1.4	0.23	0.17	1.4	1.52	1.38	0.53	0
42 d	UT	0.4	2.24	3.87	3.14	0.57	1.27	2.12	3.25	1.29	1.25	0.09
	WT	0.45	3.17	3.77	4.53	0.57	1.15	1.42	6.43	1.4	1.55	0
	ABA	0.23	3.62	7.1	2.27	0.38	0.33	1.88	3.17	1.9	1.38	0
45 d	UT	1.02	4.88	5.77	4.38	1.17	2.23	4.88	5.65	1.67	3.25	0.27
	WT	0.95	3.82	4.33	5.52	1.17	1.65	3.63	7.5	2.27	3.23	0.63
	ABA	0.88	6.37	9.08	3.63	1.27	1.58	3.67	5.77	3.3	3.1	0.03
50 d	UT	1.7	5.62	6.2	5.53	1.7	3.08	5.75	6.63	2.47	4.03	0.37
	WT	1.73	5.6	5.25	6.62	1.7	2.72	5.17	8.7	2.88	3.85	0.73
	ABA	1.75	8.2	10.15	4.87	2.18	2.47	4.63	6.38	4.03	3.57	0.13
60 d	UT	2.47	7.8	8.27	9.7	2.27	5.58	7.93	10.38	5.03	13	1.22
	WT	4.12	6.07	5.1	8	2.27	3.2	6.32	8.1	3.13	6.57	1.83
	ABA	2.47	9.87	11.13	5.57	2.23	3.53	6.37	8.17	5.2	6.93	0.22
L. S. D. at $p \leq 0.05$							1.51					

†Values are the estimated marginal means separated by Fisher's L. S. D. at $p \leq 0.05$.
††Tubers were harvested after 30 days of haulm cutting and hardened in fields for 10 days, then treated with water (WT as control) and 10 μM ABA solution then dried and stored. Untreated tubers (UT) stored directly without any treatment.

water control and at 60d compared to both water and untreated controls. ABA decreased LSL in Kufri Frysona at 30, 37, 42, 45 and 50 d compared to water control. ABA decreased LSL in Kufri Ganga, Kufri Chipsona 1 and MS/8 1148 at 60 d compared to untreated control. ABA decreased LSL in Lady Rosetta and Kufri Sindhuri at 60d compared to water control. However, ABA treatment increased LSL at 45d compared to water control and at 50 and 60d compared to both water and untreated controls in Kufri Pukhraj and at 42, 45, 50 and 60 d compared to both water and untreated controls in Kufri FryoM. In MP/06 39 also, ABA treatment increased LSL at 45 and 50d compared to untreated control and at 60d compared to water control.

Sprout numbers (Table 4) were seen low in Lady Rosetta and Kufri Sindhuri compared to other genotypes during storage. ABA treatment reduced sprout numbers in Lady Rosetta at 42d compared to both water and untreated controls. ABA treatment decreased sprout numbers in Kufri Ganga at 37 and 42 d and in Kufri Chipsona 1 at 45, 50 and 60d and in MS/8 1148 at 37, 42, 45, 50 and 60d and in Kufri Frysona and MP/06 39 at 60d compared to untreated control. However, ABA treatment increased sprout numbers at 45, 50 and 60d in Kufri Pukhraj and at 45 and 50d in Kufri FryoM compared to both

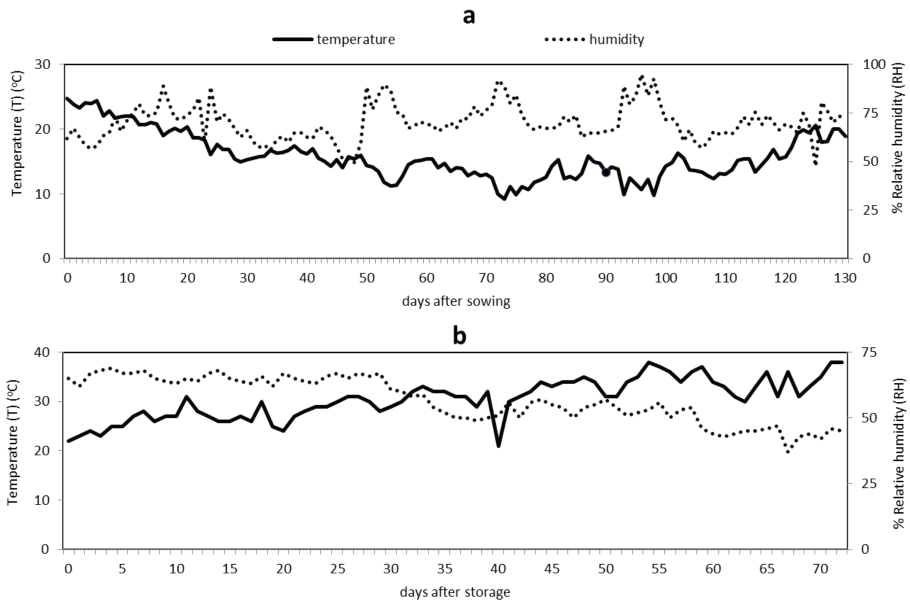

Fig. 1. Temperature and humidity during crop growth at different days after sowing (a) and during tuber storage at different days after storage (b)

Table 4: Effect of ABA treatment on sprout numbers in tubers of eleven potato genotypes at different days (d) after storage at ambient temperature

Duration	Treatment	Genotypes										
		Lady Rosetta	Kufri Pukhraj	Kufri FryoM	Kufri Neelkanth	MS/7 645	Kufri Ganga	Kufri Chipsona1	Kufri Frysona	MP/06 39	MS/8 1148	Kufri Sindhuri
30 d	UT	0	0	0.47	0.2	0.07	0.03	0.23	0.43	0.13	0	0
	WT	0	0.07	0.6	0.4	0.07	0.1	0.17	0.73	0.17	0	0
	ABA	0	0.23	0.67	0.1	0.03	0	0.28	0.47	0.3	0.1	0
37 d	UT	0.17	0.77	0.63	0.7	0.47	0.43	0.63	0.83	0.4	0.53	0
	WT	0.17	0.57	0.69	0.63	0.47	0.2	0.4	0.83	0.23	0	0
	ABA	0.07	0.8	0.8	0.77	0.37	0.13	0.43	0.77	0.4	0.23	0
42 d	UT	0.53	0.9	0.73	0.73	0.9	0.83	0.83	0.93	0.47	0.77	0.13
	WT	0.57	0.73	0.77	0.93	0.9	0.23	0.43	0.9	0.23	0.37	0
	ABA	0.23	1	1	0.83	0.93	0.27	0.57	0.97	0.43	0.3	0
45 d	UT	0.8	1.77	1.17	1.37	1.33	0.97	2.27	1.97	0.9	1.43	0.2
	WT	1	0.77	0.8	1.17	1.33	0.57	1.13	1.63	0.37	0.93	0.27
	ABA	0.9	2.27	1.53	1.2	1.3	1.17	1.47	2.07	0.9	1.07	0
50 d	UT	1.07	1.83	1.27	1.47	1.4	1.13	2.3	1.97	1.33	1.5	0.3
	WT	1.23	1.57	0.87	1.17	1.4	1.3	1.15	1.6	0.67	1.07	0.3
	ABA	1.03	2.57	1.53	1.43	1.5	1.43	1.5	2.07	1.13	1.17	0.27
60 d	UT	1.1	2.13	1.77	2	1.53	1.43	2.73	2.63	1.8	2.53	0.4
	WT	1.13	1.43	0.93	1.93	1.47	1.4	1.2	2.1	0.73	1.07	0.47
	ABA	1.33	2.93	1.63	1.83	1.52	1.37	1.7	2	1.2	1.27	0.47
L. S. D. at $p \leq 0.05$							0.3					

†Values are the estimated marginal means separated by Fisher's L. S. D. at $p \leq 0.05$.
††Tubers were harvested after 30 days of haulm cutting and hardened in fields for 10 days, then treated with water (as control) and 10 µM ABA solution then dried and stored. Untreated tubers stored directly without any treatment.

water and untreated controls. Moreover, ABA treatment increased sprout numbers compared to water control but not compared to untreated control in Kufri Chipsona 1 and MP/06 39 at 45, 50 and 60d and in Kufri Frysona at 45 and 50d. In fact, water treatment reduced sprout numbers while ABA treatment increased sprout numbers in these samples.

Tuber rottage (Table 5) was not observed in untreated tubers of Lady Rosetta, MS/7 645 and Kufri Sindhuri. ABA treatment decreased rottage in Kufri Pukhraj, Kufri FryoM, Kufri Frysona, MS/8 1148 compared to both untreated and water-treated controls. ABA treatment decreased rottage in Kufri Neelkanth, Kufri Chipsona 1 and Kufri Sindhuri compared to water control. Compared to untreated tubers, rottage was relatively high in water treated tubers in many genotypes (Kufri Pukhraj, Kufri Neelkanth, Kufri Ganga, Kufri Chipsona 1, Kufri Frysona, MS/8 1148 and Kufri Sindhuri).

ABA levels were reported to be highest in the dormant tubers at the time of harvest and levels decreased during storage (Suttle *et al.*, 2012). However, treatment of dormant tubers with exogenous ABA showed no appreciable effect on dormancy duration (Suttle *et al.*, 2012). El-Antably *et al.* (1967) indicated that ABA inhibited sprout growth when applied to the whole tubers, however, was much less effective when applied to isolated tuber plugs. Wang *et al* (2020) reported that spraying dormant tubers with 100 μM solution of ABA decreased nitric oxide (NO) content at 3 and 6 hours and reduced tuber sprouting at 20, 30, 40 and 60 days after treatment compared to water control. Present study indicated that ABA can be considered for enhancing dormancy duration in potato. In the present study, 10 μM solution of ABA was used and treatment was given once. Recently, post-harvest treatment of zucchini fruits with 500 μM solution of ABA alleviated chilling injury through activation of antioxidant defense (Castro-Cegrí *et al* 2023). In future, concentration of ABA may be increased. Secondly, water treatment relatively affected tuber quality compared to untreated samples, thus ABA may be given in gaseous form (fumigation, aerosol or dust).

Table 5: Number of rotted tubers out of thirty tubers in potato genotypes at 72 days after storage under ambient conditions

Genotype	Number of rotted tubers out of thirty		
	Untreated tubers	Water treated tubers	ABA treated tubers
Lady Rosetta	0	0	0
Kufri Pukhraj	5	13	0
Kufri FryoM	10	10	3
Kufri Neelkanth	6	10	8
MS/7 645	0	0	0
Kufri Ganga	4	8	8
Kufri Chipsona1	4	8	4
Kufri Frysona	7	13	5
MP/06 39	7	6	7
MS/8 1148	5	7	4
Kufri Sindhuri	0	1	0

In Kufri Pukhraj and Kufri FryoM, ABA treatment increased sprouting but reduced rottage. Tuber aging might be prevented by ABA. In *Phaseolus coccineus*, age-related effects of ABA were observed where in young stem, ABA promoted apical dominance but in aged stem, ABA decreased apical dominance and promoted lateral branching (Hartung and Funfer, 1981). Subapical necrosis develops on sprouts in aged tubers which are prevented by low temperature treatment or by calcium application (Coleman, 2000). Low temperature storage increases endodormancy but decreases paradormancy in potato tubers (Eshel and Teper-Bamnolker, 2012; Teper-Bamnolker *et al.*, 2012). Though ABA content decreased during tuber storage but decline in ABA was not prerequisite for dormancy exit and the onset of tuber sprouting (Biemelt

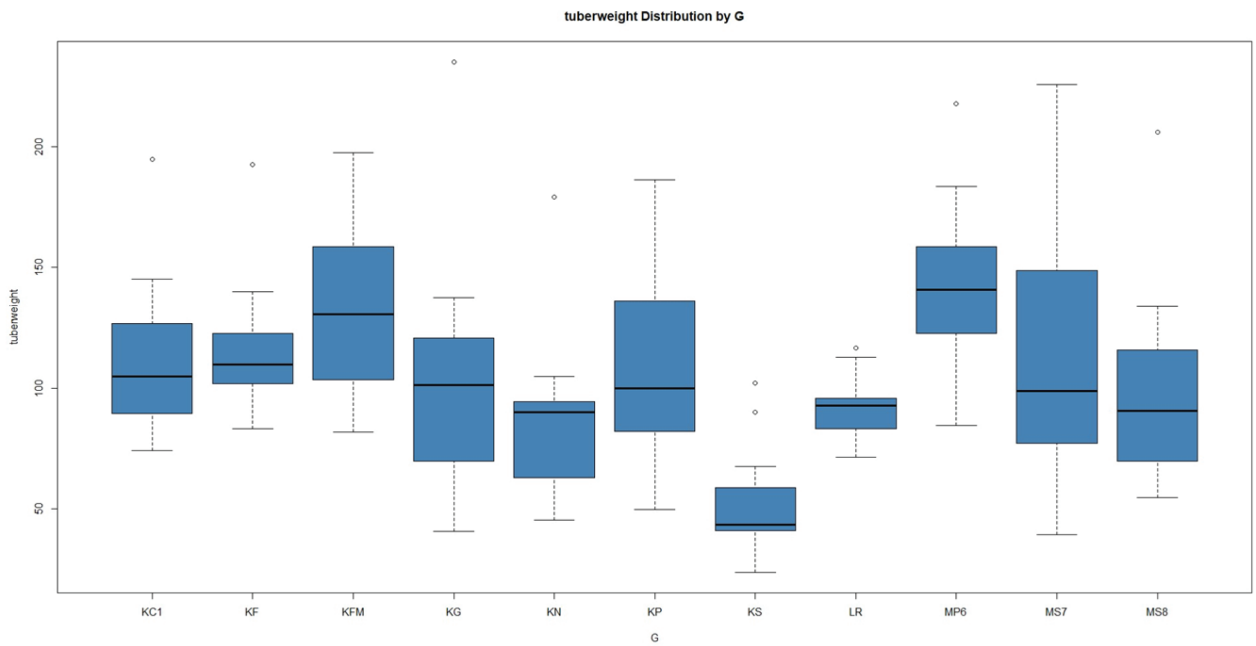

Fig. 2. Box plot showing tuber weight distribution by genotypes. Tuber weight (g tuber^{-1}) listed on y-axis while genotypes listed on x-axis. KC1, Kufri Chipsoan 1; KF, Kufri Frysona; KFM, Kufri FryoM; KG, Kufri Ganga; KN, Kufri Neelkanth; KP, Kufri Pukhraj; KS, Kufri Sindhuri; LR, Lady Rosetta; MP6, MP/06 39; MS7; MS/7 645; MS8, MS/8 114

et al., 2000; Suttle *et al.*, 2012). In addition, as sprouting approached, an unexpected increase of ABA in eyes and sub-eye regions of tubers was also reported (Sorce *et al.*, 1996). Thus, ABA may be promoting dormancy and reducing sprouting in dormant tubers. However, in sprouted tubers, ABA may enhance sprouting to prevent tuber aging.

Tuber weight

Box plot was created to visualize the distribution of tuber weight for each genotype (Fig. 2). Mean tuber weights were seen low in Lady Rosetta, Kufri Sindhuri and Kufri Neelkanth however were high in other genotypes including MS/7 645. Standard deviations (i.e., length of box plot) can be seen very high in other genotypes compared to Lady Rosetta and Kufri Sindhuri.

Ittersum and Struik (1992) found correlation coefficient = -0.82 between tuber weights and duration of tuber dormancy. The physiological age of tubers varied with the size of tubers. Tubers with diameter smaller than 35 mm had longer dormancy duration than tubers larger than 35mm (Müller *et al* 2010). Large tubers (50-60 g) exhibited faster dormancy release than smaller (10-20 g) and medium sized (30-40 g) tubers (Park *et al* 2023). Tuber weights were low in Lady Rosetta and Kufri Sindhuri however in MS/7 645, tuber weights were high compared to Lady Rosetta and Kufri Sindhuri. Uniformity of tuber size may also be an important trait as observed in Lady Rosetta and Kufri Sindhuri compared to other genotypes.

CONCLUSION

This study concluded that Lady Rosetta and Kufri Sindhuri were storable genotypes compared to other genotypes under ambient conditions. Tuber size may be an important trait related to tuber dormancy. Uniformity in tuber size may also be an important trait for tuber dormancy. ABA treatment can be used for enhancing dormancy and reducing sprouting and tuber rottage during ambient storage.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

DATA AVAILABILITY

All data generated or analysed during this study are included in this article. Requests for material should be made to the corresponding author.

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