Research Article

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Growth and yield of potato (*Solanum tuberosum* L.) as affected by storage conditions and storage duration in Jos, Plateau State, Nigeria

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Abstract: This study was carried out in two seasons (2010–2011 and 2012–2013) in Jos, Plateau State, Nigeria to investigate the growth and yield of potato (*Solanum tuberosum* L.) seed tubers as affected by storage conditions and storage duration. Five potato varieties ("Nicola," "Bertita," "Diamant," "BR63-18," and "Roslin-Ruaka") were stored for three durations (12, 24, and 32 weeks) in three kinds of stores (room temperature store [RTS], diffused light store [DLS], and air-conditioned store [ACS]). The experimental design was a split–split plot in a randomized complete block design with the potato varieties, storage conditions, and storage durations as the main, sub, and sub–sub plots, respectively. All the parameters assessed varied with variety except the plant height. Germination and establishment were significantly higher in ACS than in RTS and DLS. RTS and DLS resulted in more aboveground stems than ACS. Storage in ACS resulted in a significantly higher plant height, leaf number, total number and yield of tubers, and yield of saleable tubers in both seasons. Seed tubers stored for 24 weeks resulted in the highest establishment count and the mean number of aboveground stems in both seasons. Aboveground stems increased from 12 to 24 weeks of storage and declined at 32 weeks. Seed storage for 12 weeks resulted in the highest total number of tubers, whereas 32 weeks had the lowest number of tubers in both seasons. Seed storage for 12 and 32 weeks resulted in the highest yield of tubers in seasons 1 and 2, respectively. In conclusion, potato varieties varied greatly in the rate of physiological aging; hence, every variety required specific storage conditions and duration for optimal growth and yield.

Keywords: potato, physiological age, field growth, yield

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1 Introduction

The propagation material used to grow potato crop is the seed tuber. It is primarily propagated vegetatively via tubers although sexual propagation via botanical seed, called true potato seed, is also possible [1]. This vegetative propagation is the cheapest and easiest way of propagation even though it consists of a low multiplication rate [2]. One of the most important physiological factors associated with seed potato performance is physiological age [3,4]. Chronological and physiological age of seed tubers have major impacts on potato yield [5,6]. The essential yield components of potato crops are influenced by the physiological age of the tubers at planting [5,7].

Physiological age can be defined as the stage of development of a seed tuber, which changes progressively by increasing the chronological age and is modified by growth history and storage conditions [8–10]. Physiological age is the process of sprout development, and it depends on both the chronological age of the tubers and environmental conditions during growth in the field before storage and environmental conditions during storage. During its physiological development, the potato tuber passes through the stages of dormancy, apical dominance, multiple sprouting, and senility. During physiological aging, the tuber changes from physiologically young into physiologically old [11]. Physiologically young seed is characterized by one dominant bud that suppresses sprouting of the other buds on the tuber, a phenomenon in plants called apical dominance. In potato tubers, the result is a plant with fewer stems, fewer but larger tubers. Although physiologically older seed tubers are characterized by a loss of apical dominance, they produce multiple sprouts that emerge sooner. This means more stems, more tubers but the tubers are smaller [12].

The factors that affect the physiological aging of potato tubers have been reported to include growing conditions, storage conditions, the length of storage period, the temperature at which sprouts occur, light conditions,

the relative humidity, and competition between sprouts (the tuber size and the number of sprouts) [13]. Temperature and storage time (storage duration) have been reported to have a major influence on seed tuber physiological age [4,9,14]. Struik and Wiersema [9] suggested seed storage as a way to manage physiological age. The warmer the storage temperatures, the older the seed will become physiologically. The pattern of sprout growth of a potato tuber depends on the physiological stage of the tuber. It has been reported that, in principle, the seed should be at least 3 months old before it is planted again and not older than 5–11 months (depending on the storage method and storage temperature) [15].

Physiological age of seed potatoes strongly affects emergence, the number of stems per plants, the number of tubers per stem, the tuber size distribution, and the tuber yield of the progeny crop [9,16–18]. Time to emergence in days after planting can be variable, and tubers of different physiological statuses may have a different lag period between planting and emergence [19]. One of the main traits defining the physiological status of the seed tuber and potato plant growth vigor is the number of stems per emerged plant. The number of stems is a crucial trait as it influences tuber number both per plant and per unit area [19].

Although physiologically young potato seeds have been reported to emerge later, have fewer stems per seed tuber, show later tuberization but less secondary growth, and have more foliage growth, more tubers per stem, and a later maturity [5,16] observed, the symptoms of advanced physiological age include more rapid plant emergence and establishment, reduced apical dominance (increased stems), increased tuber set per plant, and shift in tuber size distribution. The physiological age needs to be optimized to produce a canopy and a tuber system that allow tuber production for specific outlets (seed, fresh table potato, or processing potato) [20,21].

Nigerian farmers usually store freshly harvested tubers in any convenient space within the living room (common room in a home) or in any available space within the farmstead [22]. In many cases, such buildings are poorly ventilated and stored tubers are not sorted. This results in considerable loss of the tubers. Storage losses of up to 30% in only 2 months mainly to rots and loss of moisture had been reported [23]. The tubers, therefore, shrink, shrivel, and lose weight in storage. By far, one of the major problems, which will determine the future production possibilities of potato in Nigeria, is the ability to store the tubers after harvest whether it is seed or ware potato. Available storage facilities (for family farms and commercial scale production), especially for seed, must be improved and enlarged if increased future demand for potato must be met. If a solution can be found to this problem, then both the farmer and the consumer will be better off for it because the price of potato will be much less subject to fluctuations and a more stable supply could be expected in the market throughout the year. The storage conditions affect the physiological age of the seed tubers and one of the major factors that affect essential yield components of potato crop is the physiological age of the seed tuber at planting. The objective of this study was to determine the effects of storage method and storage duration on the field production of several common potato varieties in Nigeria.

2 Materials and methods

The study was conducted during 2010–2011 (season 1) and 2012–2013 (season 2) at the National Root Crops Research Institute (NRCRI) outstation, Kuru, Jos, Plateau State, Nigeria; 09°44' N, 08°47' E at an altitude 1,239 m above sea level to investigate the effects of storage method and storage duration on field production of some potato varieties in Nigeria.

Five potato cultivars, namely "Nicola," "Bertita," "BR63-18," "Diamant," and "Roslin-Ruaka," were multiplied in the field and stored under three different storage conditions: "diffused light store (DLS)," "air-conditioned store (ACS; cooled store)," and "room temperature store (RTS; control)" for three storage durations (12, 24, and 32 weeks) and then taken to the field for planting. The storage conditions during the study have been reported by an earlier study [24]. The DLS used cool night air for cooling. The store consisted of air vents (inlet vents at the floor level and outlet vents on top of the walls opposite the inlet vents). The vents were opened at night and closed in the early hours of the morning to trap cool night air in the store. Plain and glazed glasses were fitted for illumination. The ACS was cooled with 1.5 hp split unit air conditioner and was artificially lit with low-energy bulbs. The RTS receives some light through the windows.

Storage temperature and relative humidity for each of the store types were recorded using a thermo-hygrometer (USB temperature and humidity data logger – CEM DT-172 model). Minimum and maximum temperatures for each day were calculated for each week and season (Figures 1 and 2, Appendix Tables 1 and 2).

During field evaluation, a split–split plot in a randomized complete block design was used with the potato varieties as the main plots, storage conditions as the sub plots, and storage durations as the sub–sub plots. There

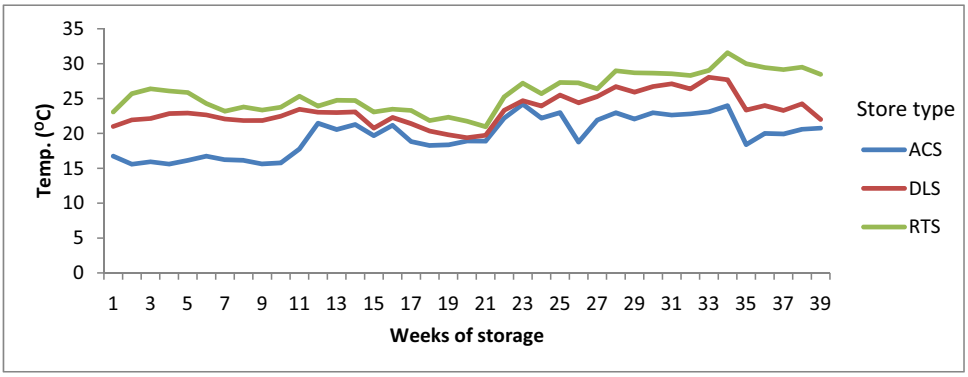

Figure 1: Maximum temperature in different store types during season 1 (2010–2011).

were 45 treatment combinations, consisting of five potato varieties, three storage types, and three storage durations replicated three times.

As each storage duration (period) was attained (12, 24, and 32 weeks), the tubers were removed from the store and taken to appropriate plots in the field. Field growth measurements taken were included: emergence/establishment count (EC) was noted at 4 weeks after planting, whereas the plant height, the number of aboveground stems, and the number of leaves/plant were measured every 2 weeks. At harvest, the following measurements were made: the total number of tubers formed per plot converted to tuber yield per meter square, the number of marketable (40 and >40 mm) tubers per meter square, the number of seed (seed >35 mm) tubers per meter square, the total yield of marketable tubers (kg/m^2), and the total yield of seed tubers (kg/m^2).

The data collected were subjected to analysis of variance as in a split–split plot design, and the means were separated by least significant difference (LSD) at 0.05 significance level using the GENSTAT Discovery Edition 4 software (VSN International).

3 Results

3.1 EC

The main effects of variety, store type, and storage duration were all significant with respect to EC during the 2010–2011 planting (first season); however, during the 2012–2013 planting (second season), the main effect of store type was not significant (Table 1). Bertita, Nicola, and Roslin-Ruaka produced a significantly higher EC than BR63-18 and Diamant in the first season. However, in the second season, Roslin-Ruaka produced the highest EC (78.52%), whereas BR63-18 produced the lowest EC (64.12%; Table 1). Storage in ACS produced a significantly higher EC (83.56%) than storage in RTS and DLS in the

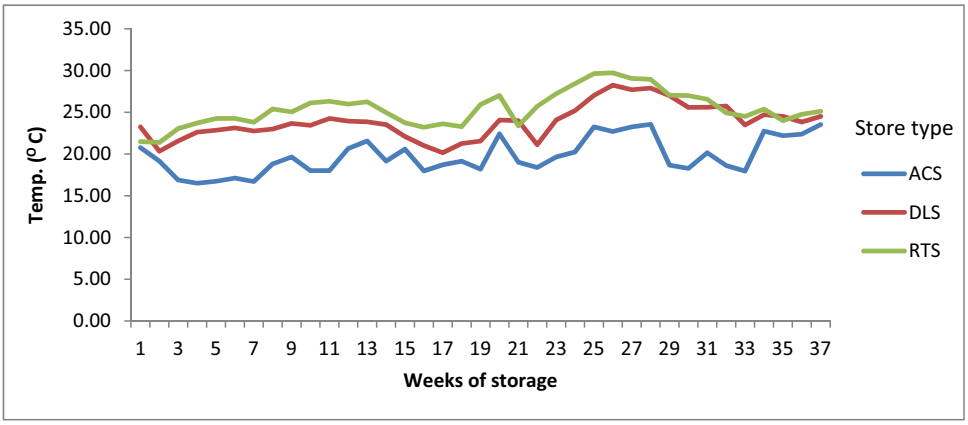

Figure 2: Maximum temperature in different store types during season 2 (2012–2013).

Table 1: Effect of variety as affected by store type and storage duration on EC, the number of aboveground stems, the plant height, and the number of leaves during two seasons (2010–2011 and 2012–2013) in Jos

Treatment	EC (%)		Aboveground stems		Plant height (cm)		Number of leaves	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
	Weeks after planting							
	4	4	12	12	12	12	12	12
Variety								
Nicola	71.85a	73.33ab	6.44a	4.42b	28.58a	38.03c	67.87a	103.20
Bertita	73.33a	68.89ab	4.88c	3.86bc	31.10a	50.67ab	50.51b	87.31
Diamant	64.44b	72.59ab	6.21ab	4.42b	28.92a	46.85b	51.93b	111.09
BR63-18	67.04b	64.12b	5.10bc	3.20c	30.29a	35.45c	48.31b	64.30
Roslin-Ruaka	70.37a	78.52a	6.15ab	5.02	24.57a	56.82a	48.19b	135.25
LS	*	*	*	**	NS	**	**	**
$LSD_{0.05}$	9.99	9.51	1.41	0.51	6.94	7.66	7.77	20.22
Storage type								
RTS	64.44b	69.33a	5.45b	4.50a	22.71b	40.23c	44.81b	92.60
DLS	60.22b	70.44a	3.52c	4.27a	17.43c	45.15b	31.64c	97.75
ACS	83.56a	75.11a	8.30a	3.78b	45.94a	51.31a	83.86a	110.34
LS	**	NS	**	**	**	**	**	*
$LSD_{0.05}$	7.74	7.38	0.70	0.39	1.99	3.46	6.48	14.06
Storage duration (weeks)								
12	84.44a	73.11b	4.41c	4.14b	28.23b	37.72c	52.40b	73.80
24	87.56a	90.89a	7.27a	5.40a	24.03c	46.10b	43.27c	102.11
32	36.22b	50.89c	5.58b	3.01c	33.82a	52.88a	64.56a	124.78
LS	**	**	**	**	**	**	**	**
$LSD_{0.05}$	7.74	7.38	0.75	0.44	2.83	4.38	6.37	15.39
Interaction								
Variety × storage duration	**	*	*	**	**	**	**	*
Variety × store type	**	**	**	*	**	*	**	**
Storage duration × store type	**	**	**	**	**	**	**	*

LS, level of significance; *, significant; and **, highly significant. Different letters in the same column indicate significant differences at $P < 0.05$; LSD, least significant difference; and NS, not significant at 5% probability level.

first season (Table 1). In both seasons, storage of tubers for 24 weeks resulted in the highest EC, whereas storage for 32 weeks produced a significantly lower EC (Table 1). The interactions of variety × storage duration, variety × store type, and storage duration × store type significantly influenced EC ($P < 0.05$; Table 1).

3.2 Variety × store type interaction on the mean EC

During the first season, Nicola produced the highest EC (87.78%) in the RTS. In the DLS, all the varieties had similar EC. In the ACS, Nicola produced the lowest EC (66.67%). In the second season, all the varieties produced a similar EC in the RTS and DLS. However, in the ACS, Roslin-Ruaka produced the highest EC (87.78%; Table 2).

3.3 Variety × storage duration interaction on the mean EC

During season 1, at 12 weeks of storage (WOS), BR63-18 produced the highest EC, and at 24 WOS, Bertita produced 100% EC although it was similar to Nicola and Roslin-Ruaka. At 32 WOS, Nicola produced the highest EC (Table 3). During season 2, Nicola produced a significantly lower EC at 12 WOS, at 24 WOS, all the varieties produced a similar EC and at 32 WOS, Nicola produced the highest EC (Table 3).

Table 2: Interaction of variety and store type on the mean EC of plants at 4 weeks after planting, the number of aboveground stems, the plant height, and the number of leaves during two seasons (2010–2011 and 2012–2013)

Treatment	Season 1 (2010–2011)			Season 2 (2012–2013)		
	Store type			Store type		
	RTS	DLS	ACS	RTS	DLS	ACS
Variety	EC (%)					
Nicola	87.78a	61.11a	66.67b	77.78a	72.22a	70.00bc
Bertita	72.22ab	66.67a	81.11a	66.67a	64.44a	75.56abc
Diamant	51.11c	58.89a	83.33ab	67.78a	66.67a	83.33ab
BR63-18	51.11c	57.78a	92.22a	65.56a	70.00a	58.89c
Roslin-Ruaka	60.00bc	56.67a	94.44a	68.89a	78.89a	87.78a
$LSD_{0.05}$	17.28			16.47		
	Aboveground stems					
Nicola	9.58a	3.50a	6.10b	5.22a	4.64b	3.40b
Bertita	4.65bc	3.01a	6.99b	4.33b	3.80bc	3.47b
Diamant	5.10b	4.07a	9.46a	4.38b	4.49ab	4.38a
BR63-18	3.27c	3.09a	8.92a	2.90c	3.36c	3.36b
Roslin-Ruaka	6.62bc	3.83a	9.99a	5.66a	5.08a	4.31a
$LSD_{0.05}$	1.78			0.83		
	Plant height					
Nicola	34.28a	12.75b	38.70c	38.42bc	36.70c	38.98b
Bertita	21.42b	19.61ab	52.27a	46.86ab	51.04ab	54.10a
Diamant	21.08b	17.20ab	48.48ab	36.20c	42.76bc	61.60a
BR63-18	20.28b	22.72a	47.88ab	26.48d	38.46c	41.41b
Roslin-Ruaka	16.48b	14.86b	42.35bc	53.20a	56.78a	60.47a
$LSD_{0.05}$	7.48			9.35		
	Number of leaves					
Nicola	109.4a	37.80a	98.10ab	98.30b	86.20bc	87.20b
Bertita	43.3b	37.80a	94.40b	84.90b	83.60bc	95.50b
Diamant	39.4b	36.50a	112.00a	82.00b	121.80ab	162.20a
BR63-18	33.0b	39.00a	100.7ab	30.30c	52.20c	76.60b
Roslin-Ruaka	41.2b	38.70a	94.00b	150.20a	156.60a	165.60a
$LSD_{0.05}$	16.88			41.68		

Different letters in the same column indicate significant differences at $P < 0.05$; RTS, room temperature store; DLS, diffused light store; and ACS, air-conditioned store.

3.4 Store type × storage duration interaction on the mean EC

During both seasons, at 12 WOS, ACS produced a significantly lower EC than RTS and DLS. At 24 WOS, a similar EC was obtained for all the store types. At 32 WOS, ACS produced a significantly higher EC (83.33%) than RTS and DLS (Table 4).

3.5 The number of aboveground stems

The main effects of variety, store type, and storage duration on the number of aboveground stems were significant ($P < 0.05$) in both seasons (Table 1). Nicola and Roslin-Ruaka produced the highest stem number in seasons 1 and 2, respectively (Table 1). During season 1, ACS produced the highest stem number. However, in season 2, RTS and DLS produced a similar and significantly higher stem number than ACS. Tuber storage for 24 weeks produced the highest stem number in both seasons (Table 1). There was a significant interaction between variety × store type, variety × storage duration, and storage duration × store type (Table 1).

3.6 Variety × store type interaction on the mean stem number

During season 1, Nicola produced the highest stem number in RTS. In the DLS, all the varieties produced similar stem number, and in ACS, Roslin-Ruaka, BR63-18, and Diamant

Table 3: Interaction of variety and the storage duration on EC, the stem number, the plant height, and the number of leaves during two seasons (2010–2011 and 2012–2013)

Treatment	Season 1 (2010–2011)			Season 2 (2012–2013)		
	Storage duration (weeks)			Storage duration (weeks)		
	12	24	32	12	24	32
Variety	EC					
Nicola	67.78b	97.78a	50.00a	45.56b	93.33a	81.11a
Bertita	76.67b	100.00a	43.33ab	74.44a	78.99a	53.33b
Diamant	93.33ab	71.11b	28.89b	87.78a	96.67a	33.33c
BR63-18	95.56a	75.56b	30.00b	71.11a	91.11a	32.22c
Roslin-Ruaka	88.89ab	93.33a	28.89b	86.67a	96.44a	54.44b
$LSD_{0.05}$	17.28			16.77		
	Aboveground stems					
Nicola	3.73a	7.29a	8.29a	4.27a	5.02b	3.98a
Bertita	3.67a	7.48a	3.51c	4.36a	4.36b	2.88b
Diamant	5.04a	7.53a	6.06b	4.47a	6.47a	2.31bc
BR63-18	4.53a	6.12a	4.64b	3.20b	4.49b	1.92c
Roslin-Ruaka	5.09a	7.93a	5.42b	4.42a	6.69a	3.93a
$LSD_{0.05}$	1.86			0.92		
	Plant height (cm)					
Nicola	16.74d	20.08b	48.90a	27.56b	39.57b	46.98c
Bertita	24.05cd	34.60a	34.66b	39.69a	48.46ab	63.85b
Diamant	32.26ab	22.57b	31.92bc	44.49a	48.82ab	47.24c
BR63-18	39.72a	25.47b	25.68c	35.89ab	40.89ab	29.49d
Roslin-Ruaka	28.37bc	17.41b	27.92bc	40.96a	52.67a	76.82a
$LSD_{0.05}$	8.22			10.53		
	Number of leaves					
Nicola	56.60ab	52.80ab	135.90a	70.10ab	64.90a	136.60b
Bertita	53.40b	62.50a	59.60c	62.20b	58.20a	143.60b
Diamant	66.70ab	45.20b	76.00b	113.90a	86.20a	165.90b
BR63-18	70.90a	41.60b	60.20bc	55.60b	39.60a	63.80c
Roslin-Ruaka	67.80ab	50.50ab	55.50c	93.50ab	83.70a	295.20a
$LSD_{0.05}$	16.34			46.66		

Different letters in the same column indicate significant differences at $P < 0.05$.

produced a similar and significantly higher stem number than Nicola and Bertita (Table 2). In season 2, Roslin-Ruaka and Nicola produced the highest stem number in RTS. Roslin-Ruaka was the highest in DLS, whereas Diamant and Roslin-Ruaka produced the highest stem number in ACS (Table 2).

3.7 Variety × storage duration interaction on the mean stem number

In season 1, at 12 and 24 WOS, all the varieties produced a similar stem number but at 32 WOS, Nicola produced the highest stem number (Table 3). During season 2, at 12 WOS, all the varieties produced a similar stem number except BR63-18. At 24 WOS, Roslin-Ruaka and Diamant produced a significantly ($P < 0.05$) higher mean stem number. At 32 WOS, Nicola and Roslin-Ruaka produced the highest stem number (Table 3).

3.8 Store type × storage duration interaction on the mean stem number

In season 1, at 12 WOS, tubers stored in all the store types produced a similar stem number. At 24 WOS, tubers stored in RTS produced a significantly higher stem number (8.63). At 32 WOS, tubers stored in ACS produced the highest stem number (Table 4). During season 2, at 12 WOS, tubers stored in ACS produced a significantly lower stem number. The same pattern was repeated at 24 WOS, but at 32 WOS, tubers stored in ACS had the highest number (3.81; Table 4).

Table 4: Interaction of store type and storage duration on the mean EC, the number of aboveground stems, the plant height, and the number of leaves during two seasons (2010–2011 and 2012–2013)

Treatment	Season 1 (2010–2011)			Season 2 (2012–2013)		
	Storage duration (weeks)			Storage duration (weeks)		
	12	24	32	12	24	32
Store type	EC					
RTS	94.00a	80.00a	19.33b	88.00a	89.22a	30.67b
DLS	87.33a	89.33a	4.00c	81.33a	91.33a	38.67b
ACS	72.00b	93.33a	85.33a	50.00b	92.00a	83.33a
$LSD_{0.05}$	13.41			12.78		
	Number of aboveground stems					
RTS	4.35a	8.63a	3.37b	4.81a	6.52a	2.16c
DLS	4.52a	6.03b	—	4.17a	5.68b	2.97b
ACS	4.37a	7.16b	13.38a	3.44b	4.01c	3.81a
$LSD_{0.05}$	1.25			0.72		
	Plant height (cm)					
RTS	31.68a	22.82a	13.63b	35.87a	45.27a	39.66c
DLS	28.96ab	23.32a	—	38.97a	44.45a	52.02b
ACS	24.05b	25.94a	87.82a	38.31a	48.68a	66.95a
$LSD_{0.05}$	4.42			6.99		
	Number of leaves					
RTS	67.80a	48.50a	43.50b	77.70a	61.50a	128.10b
DLS	67.40ab	46.50a	—	77.70a	64.00a	158.50b
ACS	54.10b	56.60a	188.80a	81.70a	74.10a	196.40a
$LSD_{0.05}$	13.52			35.87		

Different letters in the same column indicate significant differences at $P < 0.05$; RTS, room temperature store; DLS, diffused light store; and ACS, air-conditioned store.

3.9 Plant height

All main effects were significant in the first and second seasons except the main effect of variety in the first season (Table 1). Roslin-Ruaka produced the tallest plants, whereas BR63-18 and Nicola produced the shortest plants in season 2. Storage in ACS produced the tallest plants in both seasons (Table 1). Storage of seed tubers for 32 weeks produced the tallest plants in both seasons (Table 1).

3.10 Variety × store type interaction on the mean plant height

During the first season, Nicola, BR63-18, and Bertita produced the tallest plants in RTS, DLS, and ACS, respectively (Table 2). During the second season, Roslin-Ruaka produced the tallest plants in RTS and DLS, whereas Diamant, Roslin-Ruaka, and Bertita produced similar and tallest plants in the ACS (Table 2).

3.11 Variety × storage duration interaction on the mean plant height

During season 1, at 12, 24, and 32 WOS, BR63-18, Bertita, and Nicola produced the tallest plants, respectively (Table 3). In season 2, at 12, 24, and 32 WOS, Diamant, Roslin-Ruaka, and Roslin-Ruaka produced the tallest plants (Table 3).

3.12 Store type × storage duration interaction on the mean plant height

In season 1, at 12 WOS, RTS produced the tallest plants. At 24 WOS, all the store types produced a similar plant height. At 32 WOS, ACS produced the tallest plants (Table 4). In season 2, at 12 and 24 WOS, all the store types produced a similar plant height; however, at 32 WOS, tubers stored in ACS produced the tallest plants (Table 4).

3.13 The number of leaves

All main effects were significant in both seasons (Table 1). Nicola and Roslin-Ruaka produced the highest number of leaves in seasons 1 and 2, respectively. Storage in ACS produced the highest number of leaves in both seasons. The 32 weeks storage treatments led to the highest number of leaves in both seasons (Table 1). There were significant interactions of variety × store type, variety × storage duration, and store type × storage duration (Table 1).

3.14 Variety × store type interaction on the mean number of leaves

In season 1, Nicola produced the highest number of leaves in the RTS. In the DLS, all the varieties produced a similar number of leaves. In the ACS, Diamant produced the highest number of leaves (Table 2). During season 2, Roslin-Ruaka produced the highest number of leaves in the RTS. In the DLS and ACS, Roslin-Ruaka and Diamant produced similar numbers of leaves (Table 2).

3.15 Variety × storage duration interaction on the mean number of leaves

During season 1, at 12, 24, and 32 WOS, BR63-18, Bertita, and Nicola produced the highest mean number of leaves, respectively (Table 3). In season 2, at 12 WOS, Diamant had the highest number of leaves. At 24 WOS, all the varieties produced a similar number of leaves, whereas at 32 WOS, Roslin-Ruaka produced the highest number of leaves (Table 3).

3.16 Storage duration × store type interaction on the mean number of leaves

During season 1, at 12 WOS, RTS had the highest number of leaves. At 24 WOS, all the store types produced a similar number of leaves. At 32 WOS, ACS produced the highest number of leaves (Table 4). During season 2, at 12 and 24 WOS, all the store types produced a similar number of leaves. At 32 WOS, ACS produced the highest number of leaves (Table 4).

3.17 The total number of tubers formed

The main effects of variety, store type, and storage duration were all significant ($P < 0.05$) with respect to the total number of tubers formed in season 1; however, in the second season, the main effect of store types was not significant (Table 5). All the varieties produced a similar number of tubers except Nicola, which was significantly higher at 18.68 tubers/m^2 in season 1. In season 2, Nicola was the highest, whereas BR63-18 was the lowest. ACS produced the highest number of tubers (16.63 tubers/m^2). Tuber storage for 12 weeks produced the highest number of tubers in both seasons (Table 5). There were significant interactions of variety × storage duration, variety × storage type, and storage duration × store type in season 1. Variety × storage type interaction was not significant in season 2 (Table 5).

3.18 Variety × store type interaction on the total number of tubers formed

During season 1, in the RTS Nicola produced a significantly higher tuber number than the other varieties that were similar. In the DLS, Nicola was the highest but similar to BR63-18 and Roslin-Ruaka. In the ACS, Nicola was the highest but similar to BR63-18 and Roslin-Ruaka (Table 6).

3.19 Variety × storage duration interaction on the total number of tubers formed

During season 1, at 12, 24, and 32 WOS, BR63-18 and Nicola produced the highest number of tubers per meter square, respectively (Table 7). In season 2, Nicola produced the highest (40.93 tubers/m^2) after 12 WOS; after 24 WOS, Nicola, Bertita, and Roslin-Ruaka produced a similar number of tubers per meter square; and after 32 WOS, Nicola was the highest, whereas Bertita, Diamant and Roslin-Ruaka produced similar tubers per meter square (Table 7).

3.20 Store type × storage duration interaction on the total number of tubers formed

During season 1, at 12 and 24 WOS, a similar number of tubers per meter square were produced for all the store types. At 32 WOS, ACS produced the highest number of

Table 5: Effect of variety as affected by store type and storage duration on the total number of tubers, the number of ware tubers, the number of seed tubers, the total yield of tubers, the yield of ware tubers, and the yield of seed tubers during two seasons (2010–2011 and 2012–2013)

Treatment	Total number of tubers per meter square		Number of ware tubers per meter square		Number of seed tubers per meter square		Total yield of tubers (kg/m^2)		Yield of ware tubers (kg/m^2)		Yield of seed tubers (kg/m^2)	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Variety												
Nicola	18.68a	37.98a	1.70bc	8.14a	16.98a	29.82a	0.30b	0.74a	0.13b	0.48a	0.21a	0.25a
Bertita	11.54b	15.01d	3.00a	5.22b	8.54d	9.89d	0.40a	0.66ab	0.23a	0.54a	0.14b	0.12b
Diamant	12.11b	24.64bc	1.33c	4.70b	10.90bc	19.94bc	0.24b	0.51b	0.07d	0.29bc	0.17ab	0.22a
BR63-18	13.73b	18.65cd	1.41c	3.09c	12.46b	16.01c	0.82b	0.33c	0.09cd	0.17c	0.18ab	0.22a
Roslin-Ruaka	12.32b	26.81b	1.94b	5.14b	10.41c	21.23b	0.29b	0.57b	0.11bc	0.34b	0.17ab	0.21a
LS	**	**	**	**	**	*	**	**	*	**	**	*
$LSD_{0.05}$	1.91	5.24	0.45	1.61	1.68	4.44	0.04	0.16	0.04	0.12	0.02	0.09
Storage type												
RTS	12.89b	23.55a	1.41b	3.04c	11.56b	20.78a	0.28b	0.37c	0.09b	0.18c	0.17a	0.23a
DLS	11.51b	23.21a	1.27b	4.20b	10.21b	19.01a	0.24b	0.47b	0.08b	0.28b	0.16a	0.18a
ACS	16.63a	27.10a	2.95a	8.53a	13.79a	18.35a	0.38a	0.83a	0.19a	0.63a	0.19a	0.20a
LS	**	NS	**	**	**	NS	**	**	*	**	NS	NS
$LSD_{0.05}$	1.50	4.22	0.30	1.25	1.56	3.44	0.04	0.11	0.03	0.09	0.03	0.07
Storage duration (weeks)												
12	23.68a	29.61a	2.95a	4.48b	20.79a	25.40a	0.60a	0.61b	0.20a	0.31b	0.37a	0.32a
24	10.52b	21.19b	1.15c	2.15c	9.48b	18.77b	0.16b	0.24c	0.05c	0.13c	0.11b	0.11c
32	6.83c	23.06b	1.53b	9.14a	5.30c	13.97c	0.14b	0.84a	0.10b	0.65a	0.04c	0.18b
LS	**	**	**	**	**	*	**	**	*	**	**	*
$LSD_{0.05}$	1.86	3.70	0.33	1.25	1.74	3.44	0.04	0.10	0.03	0.09	0.03	0.07
Interaction												
Variety × storage duration	**	**	**	**	**	*	**	**	*	**	**	*
Variety × store type	**	NS	**	*	**	**	*	*	*	*	*	*
Storage duration × store type	**	**	**	**	**	**	**	**	*	**	*	**

LS, level of significance; *, significant; and **, highly significant. Different letters in the same column indicate significant differences at $P < 0.05$; LSD, least significant difference; and NS, not significant at 5% probability level.

tubers per meter square (13.90), whereas RTS was the lowest. In season 2, Nicola and Bertita produced a similar number of tubers per meter square (Table 8).

3.21 The number of ware tubers formed

The main effects of variety, storage type, and storage duration were all significant ($P < 0.05$) with respect to the number of ware tubers formed in both seasons (Table 5). Bertita and Nicola produced the highest number of ware tubers in seasons 1 and 2, respectively. ACS produced the highest number of ware tuber of both seasons (Table 5). The 12 WOS produced the highest number of ware tubers in season 1, whereas 32 WOS produced the highest number of ware tubers in season 2. There were significant ($P < 0.05$) interactions of variety × store type, variety × storage duration, and storage duration × store type (Table 5).

3.22 Variety × store type interaction on the number of ware tubers formed

During season 1, Bertita produced the highest number of ware tubers (3.03 tubers/m^2), whereas all the other varieties were similar in the RTS. With DLS, Bertita was the highest (2.48 tubers/m^2), whereas Diamant was the lowest. With ACS, Nicola, Bertita, and Roslin-Ruaka had a similar

Table 6: Interaction of variety and store type on the total number of tubers, the number of ware tubers, the number of seed tubers, the total yield of tubers, the yield of ware tubers, and the yield of seed tubers during two seasons (2010–2011 and 2012–2013)

Treatment	Season 1 (2010–2011)			Season 2 (2012–2013)		
	Store type			Store type		
	RTS	DLS	ACS	RTS	DLS	ACS
Variety	Total number of tubers per meter square					
Nicola	23.60a	13.57a	18.90a			
Bertita	10.87b	10.27b	13.53c			
Diamant	11.30b	10.03b	15.00c			
BR63-18	9.60b	12.90ab	18.70a			
Roslin-Ruaka	9.10b	10.80ab	17.03ab			
$LSD_{0.05}$	3.18					
	Number of ware tubers per meter square					
Nicola	0.96b	0.85bc	3.30a	5.48a	7.52a	11.40a
Bertita	3.30a	2.48a	3.22a	3.33b	4.30b	8.04b
Diamant	1.11b	0.70c	2.19b	1.63b	2.30b	10.19ab
BR63-18	0.56b	0.85bc	2.81ab	2.33b	2.33b	4.59c
Roslin-Ruaka	1.11b	1.48b	3.22a	2.41	4.56b	8.44b
$LSD_{0.05}$	0.66			2.79		
	Number of seed tubers per meter square					
Nicola	22.63a	12.70a	15.60a	38.14a	27.37a	23.96a
Bertita	7.57b	7.77c	10.30b	7.22d	11.26c	11.19c
Diamant	10.20b	9.33bc	13.20ab	19.00bc	19.33b	21.48ab
BR63-18	9.43b	12.03ab	15.90a	15.37c	17.00bc	15.67bc
Roslin-Ruaka	8.00b	9.23bc	14.00a	24.15b	20.11ab	19.44ab
$LSD_{0.05}$	3.16			7.69		
	Total yield of tubers (kg/m^2)					
Nicola	0.31b	0.20b	0.39a	0.63a	0.69a	0.90ab
Bertita	0.42a	0.32a	0.46a	0.37b	0.53ab	1.08a
Diamant	0.26bc	0.19b	0.27b	0.28b	0.35b	0.90ab
BR63-18	0.18c	0.25ab	0.38a	0.20b	0.32b	0.46c
Roslin-Ruaka	0.22c	0.75ab	0.38a	0.39ab	0.48ab	0.83b
$LSD_{0.05}$	0.08			0.25		
	Yield of ware tubers (kg/m^2)					
Nicola	0.05b	0.04b	0.19b	0.30a	0.43a	0.71b
Bertita	0.21a	0.19a	0.29a	0.28ab	0.40a	0.93a
Diamant	0.08b	0.03b	0.11c	0.10bc	0.16b	0.61b
BR63-18	0.03b	0.06b	0.18b	0.07c	0.14b	0.31c
Roslin-Ruaka	0.07b	0.07b	0.19b	0.16bc	0.27ab	0.61b
$LSD_{0.05}$	0.06			0.20		
	Yield of seed tubers (kg/m^2)					
Nicola	0.25a	0.16a	0.21a	0.33a	0.22a	0.19a
Bertita	0.13b	0.13b	0.16a	0.08c	0.13a	0.16a
Diamant	0.18b	0.16ab	0.15a	0.18bc	0.19a	0.29a
BR63-18	0.15b	0.19a	0.20a	0.32a	0.18a	0.16a
Roslin-Ruaka	0.15b	0.15ab	0.20a	0.23bc	0.22a	0.19a
$LSD_{0.05}$	0.06			0.15		

Different letters in the same column indicate significant differences at $P < 0.05$.

and the highest number of ware tubers (Table 6). In season 2, Nicola produced the highest number of ware tubers, whereas the other varieties were similar in the RTS and DLS, respectively. With the ACS, Nicola and Diamant produced a similar and higher number of ware tubers, whereas BR63-18 was the lowest (Table 6).

3.23 Variety × storage duration interaction on the number of ware tubers formed

During season 1, at 12 and 24 WOS, Bertita produced the highest number of ware tubers. At 32 WOS, Nicola

Table 7: Interaction of variety and storage duration on the total number of tubers, the number of ware tubers, the number of seed tubers, the total yield of tubers, the yield of ware tubers, and the yield of seed tubers during two seasons (2010–2011 and 2012–2013)

Treatment	Season 1 (2010–2011)			Season 2 (2012–2013)		
	Storage duration (weeks)			Storage duration (weeks)		
	12	24	32	12	24	32
Variety	Total number of tubers per meter square					
Nicola	25.37b	14.40a	16.27a	40.93a	27.37a	45.63a
Bertita	20.30c	11.43ab	2.90b	16.87c	9.90b	18.30b
Diamant	21.97bc	8.87bc	5.53b	28.97b	25.90a	19.07b
BR63-18	30.03a	6.70c	4.43b	31.47b	14.87b	9.63c
Roslin-Ruaka	22.07bc	11.19ab	5.04b	29.87b	27.93a	22.67b
$LSD_{0.05}$	3.78			8.18		
	Number of ware tubers per meter square					
Nicola	1.89c	1.11bc	2.11a	2.63b	3.11a	18.67a
Bertita	6.37a	1.63a	1.00b	6.29a	2.30a	7.07b
Diamant	2.07bc	0.67c	1.26b	5.15a	1.07a	7.89b
BR63-18	1.78c	0.85bc	1.59ab	4.11a	2.67a	2.48c
Roslin-Ruaka	2.63b	1.48b	1.70ab	4.22a	1.59a	9.59b
$LSD_{0.05}$	0.72			3.20		
	Number of seed tubers per meter square					
Nicola	23.47b	13.30a	14.13a	38.30a	24.26a	26.93a
Bertita	13.93d	9.80b	1.90b	10.56c	7.59b	11.52b
Diamant	19.90c	8.57bc	4.27b	23.81b	24.81a	11.19b
BR63-18	28.67a	5.87c	2.87b	28.70b	12.19b	7.15b
Roslin-Ruaka	18.00c	9.00bc	3.33b	25.63b	25.00a	13.07b
$LSD_{0.05}$	3.48			8.40		
	Total yield of tubers (kg/m^2)					
Nicola	0.48c	0.19a	0.23a	0.56ab	0.28a	1.39a
Bertita	0.84a	0.24a	0.11b	0.76a	0.24a	0.97b
Diamant	0.53bc	0.09b	0.10b	0.68ab	0.17a	0.67b
BR63-18	0.57b	0.11b	0.14b	0.38b	0.28a	0.23c
Roslin-Ruaka	0.57b	0.17a	0.12b	0.56ab	0.21a	0.93b
$LSD_{0.05}$	0.08			0.23		
	Yield of ware tubers (kg/m^2)					
Nicola	0.11b	0.04a	0.13a	0.17b	0.14a	1.13a
Bertita	0.50a	0.09a	0.10a	0.60a	0.19a	0.83ab
Diamant	0.13b	0.02a	0.07a	0.35b	0.05a	0.47c
BR63-18	0.11b	0.05a	0.10a	0.19b	0.18a	0.15d
Roslin-Ruaka	0.16b	0.07a	0.10a	0.26b	0.08a	0.69b
$LSD_{0.05}$	0.07			0.22		
	Yield of seed tubers (kg/m^2)					
Nicola	0.37b	0.15a	0.10a	0.34ab	0.14a	0.26a
Bertita	0.26c	0.15a	0.02b	0.16c	0.06a	0.14a
Diamant	0.40b	0.07b	0.03b	0.33ab	0.12a	0.20a
BR63-18	0.46a	0.06b	0.03b	0.48a	0.10a	0.07b
Roslin-Ruaka	0.37b	0.11ab	0.02b	0.30bc	0.13a	0.21a
$LSD_{0.05}$	0.05			0.16		

Different letters in the same column indicate significant differences at $P < 0.05$.

produced the highest (Table 7). In season 2, all the varieties produced a similar number of ware tubers except Nicola, which was significantly lower after 12 WOS. At 24 WOS, all the varieties produced a similar number of ware tubers, and at 32 WOS, Nicola was the highest, whereas BR63-18 was the lowest (Table 7).

3.24 Storage type × storage duration interaction on the number of ware tubers formed

During season 1, at 12 and 24 WOS, all the store types produced a similar number of ware tubers per meter

Table 8: Interaction of store type and storage duration on the total number of tubers, the number of ware tubers, the number of seed tubers, the total yield of tubers, the yield of ware tubers, and the yield of seed tubers during two seasons (2010–2011 and 2012–2013)

Treatment	Season 1 (2010–2011)			Season 2 (2012–2013)		
	Storage duration (weeks)			Storage duration (weeks)		
	12	24	32	12	24	32
Store type	Total number of tubers per meter square					
RTS	22.70a	9.37a	6.60b	32.30a	26.33a	12.13b
DLS	24.17a	10.37a	—	33.50a	20.30b	15.83b
ACS	24.17a	11.83a	13.90a	23.07b	17.03b	41.20a
$LSD_{0.05}$	2.99			6.59		
	Number of ware tubers per meter square					
RTS	3.16a	0.73b	0.33b	4.05a	1.09b	3.87b
DLS	2.82a	1.00b	—	4.82a	1.91a	5.87b
ACS	2.87a	1.71a	4.27a	4.47a	3.44a	17.69a
$LSD_{0.05}$	0.55			2.16		
	Number of seed tubers per meter square					
RTS	19.80a	8.63a	6.20b	28.93a	25.13a	8.27b
DLS	21.27a	9.37a	—	28.67a	18.40b	9.98b
ACS	21.20a	10.43a	9.63a	18.60b	12.78c	23.67a
$LSD_{0.05}$	2.86			2.88		
	Total yield of tubers (kg/m^2)					
RTS	0.64a	0.13b	0.07b	0.58a	0.21a	0.33b
DLS	0.58b	0.15ab	—	0.72a	0.21a	0.49b
ACS	0.58b	0.20a	0.35a	0.52b	0.29a	1.69a
$LSD_{0.05}$	0.06					
	Yield of ware tubers (kg/m^2)					
RTS	0.21a	0.03a	0.02b	0.25a	0.06a	0.24b
DLS	0.18a	0.04a	—	0.36a	0.11a	0.38b
ACS	0.18a	0.04a	0.28a	0.33a	0.21a	1.35a
$LSD_{0.05}$	0.05			0.16		
	Yield of seed tubers (kg/m^2)					
RTS	0.38a	0.10a	0.04a	0.45a	0.14a	0.09b
DLS	0.38a	0.11a	—	0.33a	0.11a	0.12b
ACS	0.36a	0.11a	0.08a	0.19b	0.33a	0.33a
$LSD_{0.05}$	0.05			0.12		

Different letters in the same column indicate significant differences at $P < 0.05$; RTS, room temperature store; DLS, diffused light store; and ACS, air-conditioned store.

square. At 32 WOS, ACS produced the highest number of ware tubers per meter square (Table 8).

3.25 The number of seed tubers

The main effects of variety, store type, and storage duration were all significant ($P < 0.05$) with respect to the mean number of seed tubers in the first season; however, in the second season, the main effect of store type was not significant (Table 5). Nicola produced the highest number of seed tubers in both seasons. ACS produced the highest number of seed tubers in season 1. Storage of tubers for 12 weeks produced the highest number of seed tubers in both seasons. All interactions were significant with respect to the number of seed tubers produced (Table 5).

3.26 Variety × store type interaction on the number of seed tubers

During the first season, Nicola produced the highest number of seed tubers, whereas all other varieties were similar in the RTS. With the DLS, Nicola was significantly higher than Bertita. With ACS, Nicola, BR63-18, and Roslin-Ruaka produced a similar and the highest number of seed tubers (Table 6). In season 2, Nicola produced the

highest number of seed tubers in all the store types, whereas the other varieties were significantly different (Table 6).

3.27 Variety × storage duration interaction on the number of seed tubers

During season 1, at 12 WOS, BR63-18 produced the highest number of seed tuber per meter square. At 24 WOS, Nicola was the highest (13.0 tubers/m^2). At 32 WOS, Nicola produced the highest number of seed tubers, whereas all the other varieties were similar (Table 7).

In season 2, at 12 WOS, although Nicola was the highest, Bertita produced the lowest number of seed tubers per meter square. At 24 WOS, Nicola, Diamant, and Roslin-Ruaka produced a similar and the highest number of seed tubers. At 32 WOS, Nicola was the highest, whereas all other varieties produced a similar number of seed tubers per meter square (Table 7).

3.28 Storage duration × store type interaction on the number of seed tubers

During season 1, at 12 and 24 WOS, all the store types produced a similar number of seed tubers. At 32 WOS, ACS produced the highest number of seed tubers (Table 8). During season 2 at 12 WOS, ACS produced a significantly lower number of seed tubers than the other store types. At 24 WOS, RTS was the highest, whereas at 32 WOS, ACS produced the highest number of seed tubers per meter square (Table 8).

3.29 The total yield of tubers

All main effects with respect to the total yield of tubers were significant ($P < 0.05$; Table 5). Variety Betita resulted in the highest yield of 0.40 kg/m^2 in season 1, whereas Nicola had the highest yield of 0.74 kg/m^2 in season 2. Storage in ACS produced the highest yield of 0.38 kg/m^2, whereas DLS and RTS were similar in season 1. In season 2, ACS was the highest, whereas RTS had a significantly lower yield. Storage for 12 weeks produced the highest yield of 0.60 kg/m^2 in season 1. In season 2, 32 WOS produced the highest yield of 0.84 kg/m^2. All interactions were significant (Table 5).

3.30 Variety × store type interaction on the total yield of tubers

In the first season, Bertita produced the highest total yield of tubers (0.42 kg/m^2) in the RTS. In the DLS, Bertita was the highest. In the ACS, Nicola, Bertita, BR63-18, and Roslin-Ruaka produced the highest yield, whereas Diamant was significantly lower (Table 6). In season 2, Nicola and Bertita produced the highest total yield of tubers in the RTS. In the DLS, Nicola, Bertita and Roslin-Ruaka had the highest total yield of tubers. In ACS, Bertita produced the highest total yield of tubers per meter square (Table 6).

3.31 Variety × storage duration interaction on the total yield of tubers

During season 1, at 12 WOS Bertita produced the highest total yield of tubers. At 24 WOS, Nicola, Bertita, and Roslin-Ruaka had a similar and the highest total yield of tubers. At 32 WOS, Nicola had the highest total yield of tubers, whereas all other varieties were similar (Table 7). In season 2, Bertita had the highest total yield of tubers at 12 WOS, and at 24 WOS, all the varieties produced a similar total yield of tubers per meter square (Table 7). At 32 WOS, Nicola had the highest total yield of tubers (Table 7).

3.32 Storage duration × store type interaction on the total yield of tubers

During season 1, at 12 WOS, RTS produced the highest total yield of 0.64 kg/m^2. At 24 and 32 WOS, ACS produced the highest total yield of tubers (Table 8). In season 2, at 12 WOS, RTS and DLS produced a similar and the highest total yield of tubers per meter square. At 24 WOS, all the store types had a similar total yield of tubers (Table 8).

3.33 Yield of ware tubers

All main effects with respect to yield of ware tubers were significant ($P < 0.05$; Table 5). Bertita had the highest yield of ware tubers (0.23 kg/m^2) in season 1. In season 2, Bertita and Nicola had a similar and the highest yield of ware tubers. ACS resulted in the highest yield of ware tubers in both seasons (Table 5). In season 1, 12 WOS

produced the highest yield of ware tubers; however, in season 2, 32 WOS produced the highest yield of ware tubers. Interactions of variety × store type, variety × storage duration, and storage duration × store type were all significant (Table 5).

3.34 Variety × store type interaction on the yield of ware tubers

During season 1, Bertita produced the highest yield of ware tubers in RTS and DLS, whereas all other varieties were similar. In ACS, Bertita was the highest, whereas Diamant was the lowest in yield of ware tubers (Table 6). In season 2, Nicola and Bertita had the highest yield of ware tubers in the RTS and DLS. In the ACS, Bertita had the highest yield of ware tubers (Table 6).

3.35 Variety × storage duration interaction on the yield of ware tubers

During season 1, Bertita had the highest yield of ware tubers at 12 WOS. At 24 and 32 WOS, all the varieties had a similar yield of ware tubers (Table 7). In season 2, Bertita was the highest at 12 WOS. At 32 WOS, Nicola produced the highest yield (Table 7).

3.36 Storage duration × storage type interaction on the yield of ware tubers

During season 1, at 12 and 24 WOS, all the store types produced a similar yield of ware tubers (Table 8). In season 2, at 12 WOS, ACS produced a significantly lower yield of ware tubers. At 24 WOS, all the store types had a similar yield of ware tubers; however, at 32 WOS, ACS produced the highest yield of ware tuber (Table 8).

3.37 Yield of seed tubers

The main effects of variety and storage duration on the yield of seed tubers were significant in both seasons, whereas the main effect of store type was not significant ($P < 0.05$; Table 5). Variety Bertita produced a significantly lower yield of seed tubers in both seasons. Tuber storage for 12 weeks produced the highest yield of seed tubers per meter square (Table 5).

3.38 Variety × store type interaction on the yield of seed tubers

During season 1, Nicola produced a significantly higher yield of seed tubers than the other varieties that were similar in the RTS. In the DLS, Bertita produced the lowest yield of seed tubers. In the ACS, all the varieties produced a similar yield of seed tubers (Table 6).

In season 2, Nicola and BR63-18 produced the highest yield of seed tubers in the RTS. In the DLS and ACS, all the varieties produced a similar yield of seed tubers (Table 6).

3.39 Variety × storage duration interaction on the yield of seed tubers

During season 1, at 12 WOS, BR63-18 produced the highest yield of seed tubers. At 24 WOS, Nicola, Bertita, and Roslin-Ruaka had the highest yield of seed tubers. At 32 WOS, Nicola produced a significantly higher yield of seed tubers than the other varieties (Table 7).

In season 2, BR63-18 had the highest yield of seed tubers at 12 WOS. At 24 WOS, all the varieties had a similar yield of seed tubers, and at 32 WOS, BR63-18 produced a significantly lower yield of seed tubers (Table 7).

3.40 Store type × storage duration interaction on the yield of seed tubers

During season 2, at 12 WOS, ACS produced a significantly lower yield of seed tubers than the other store types. At 24 WOS all the store types had similar yield of seed tubers. At 32 WOS, ACS had the highest yield of seed tubers (Table 8).

4 Discussion

EC was generally significantly different with variety. The varietal variations may be attributed to the genetic composition of the varieties and environmental conditions;

for example, soil temperature and soil moisture during growth in the field, which also differed between storage types. It has been observed that emergence depends on physiological age of seed tubers, planting date, soil temperature, other environmental factors, and the characteristics of a particular cultivar [25]. EC varied significantly with store type and storage duration in seasons 1 and 2. RTS and DLS were characterized by a higher storage temperature than the ACS and a higher EC after 12 weeks of seed tuber storage. Physiological age has been reported to affect tuber germination and date of emergence [4].

Generally, the main effects of variety, storage duration, and store type on the mean number of aboveground stems were significant in both seasons. The variation in stem number as affected by variety could be a cultivar characteristic. Stem number has been found to be significantly affected by cultivar [2]. Mediouni et al. [4] observed that cultivar influences not only the sprouting process of tubers but also the vegetative growth and the productivity of the resulting plants. Variation in the stem number with store type may be attributed to environmental conditions in the store types especially temperature, chronological, and physiological age of the tubers. Van Loon [26] and Moll [27] reported that physiological age affected seed tubers' future crop performance from emergence to the number of emerged stems per mother tuber. Physiological quality of seed tubers has been reported to affect the quality of sprouts as well as the number of stems per plant and, therefore, the yield [4].

The difference in the plant height due to variety may be attributed to the genetic composition of the varieties. Cultivar differences in the plant height has been reported [2,28]. The plant height varied significantly ($P < 0.05$) with storage duration and store type. Vakis [29] and Moll [27] reported that physiological age of seed tubers affects future crop performance from emergence to crop vigor and growth. Mediouni et al. [4] reported that physiologically older tubers produce less vine growth.

Generally in both seasons, the main effect of variety on the number of leaves formed per plant was significant ($P < 0.05$). Varietal differences in the distribution of leaves above ground and stolon below ground have been reported [30]. Iritani [31] reported that the plants from older seed tubers had a significantly smaller foliage and considerably less vigor than seeds from young seed. It has been found that the progress from physiologically young to physiologically old affects canopy growth pattern of potato [32].

Generally, the main effect of variety on the total number of tubers formed was significant in all seasons. Nicola resulted in the highest number of tubers formed, whereas Bertita resulted in the lowest number of tubers formed in all seasons. The variation may be attributed to the genetic composition of the varieties used and environmental conditions during crop growth in the field. The number of tubers produced in a potato crop has been reported to be affected by stem population, variety, and environmental factors such as temperature, moisture, and nutrients supply [33]. The number of tubers formed has been reported to be significantly affected by variety [2,34].

The final total number of tubers formed varied with store type and storage duration. The interaction may be attributed to environmental conditions, especially temperature in the store types, physiological age of the seed tubers, and environmental conditions during crop growth in the field. Gao et al. [35] reported that during tuber initiation stage, tubers are formed on stolon, and the number of tubers carried to harvest is determined by environmental conditions during this growing stage. Growing season has been reported to have a carryover effect on the number of daughter tubers produced per seed potato [36,37].

The main effect of variety on final total yield of tubers was significant ($P < 0.05$). The tuber yield has been reported to be significantly influenced by variety for all tuber size and quality categories [38].

The final total tuber yield varied significantly with store type and storage duration. After 12 weeks of seed tuber storage, seed tubers stored in ACS resulted in the lowest yield of tubers than the RTS and DLS in all the seasons. After 32 weeks of seed tuber storage, seed tubers stored in ACS resulted in the highest yield of tubers in both season. At final harvest, the tuber yield has been reported to be higher in physiologically young seed than older ones [9,39]. The number of ware tubers formed varied significantly with variety in all the seasons. This variation may be due to genetic makeup of the varieties. The tuber yield has been reported to be significantly influenced by variety for all tuber size categories [38]. Struik et al. [21] reported that tuber size distribution is mainly dependent on the yield (i.e., a change of the average tuber size). The number of ware tubers formed varied with store type and storage duration in all the seasons.

The yield of ware tubers was significantly ($P < 0.05$) affected by variety in all the seasons. This variation may be due to genetic composition of the varieties. The yield has been reported to be significantly influenced by variety for all sizes and quality categories [38].

The yield of ware tubers varied significantly with store type and storage duration in all the seasons. After 12 and 24 weeks of seed tuber storage, all the store types

resulted in a similar yield of ware tubers in both seasons. After 32 weeks of seed tuber storage, the ACS resulted in a significantly higher yield of ware tubers in both seasons. This interaction may be attributed to environmental conditions especially temperature, physiological age of seed tubers, and environmental conditions during crop growth in the field. Tuber growth has been reported to be higher at the end of the growing season in those plants coming from physiologically young seed tubers [39]. Toosey [40] and Iritani [31] reported that as tubers aged physiologically, the plants have less potential for higher yield than plants that form physiologically young seed. Bohl et al. [41] observed that physiologically older seeds will result in reduction in plant stand, vigor, and yield. This suggests reasons why seed tubers from ACS resulted in higher yield after 32 weeks of seed tuber storage.

The final yield of seed tubers formed varied significantly with variety in all the seasons. The variation may be as a result of genetic composition of the varieties and changes in environmental conditions from season to season. Mannaf et al. [42] found that seed tuber yield varied with variety. Variety Dheera had a seed yield of 17.65 t/ha, whereas variety Iteera had a seed yield of 17.27 t/ha.

5 Conclusion

The varieties varied greatly in their rate of physiological ageing; therefore, every variety needs its own specific storage conditions to obtain optimal growth and vigor at planting.

All the store types used in the study (RTS, DLS, and ACS) are relevant to Nigerian potato farmers because they can explore/manipulate the different store types to suit their specific purpose.

(I) RTS where the storage condition is characterized by a high temperature, which will enhance early break of dormancy and sprouting and physiological ageing of seed tubers. This store will be used for short storage of seed, for example, when farmers harvest rain fed crop in July and need to plant the seed tubers on their irrigation farms by October.

(II) ACS can be used to control the high temperature and thus slow down physiological ageing of the seed tubers. This could be used for prolong storage of seed, for example, from one rain fed harvest to next year's rain fed planting.

Physiological age had marked effect on the growth and yield of potato in the field.

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References

[1] Thomas-Sharma S, Abdurahman A, Ali S, Andrade-Piedra JL, Bao S, Charkowski AO, et al. Seed degeneration in potato: The need for an integrated seed health strategy to mitigate the problem in developing countries. Plant Pathol. 2016;65(1):3–16.

[2] Otroshy M, Sruik PC. Effects of size of normal seed tubers and growth regulator application on dormancy, sprout behavior, growth vigour and quality of normal seed tubers of different potato cultivars. Res J Seed Sci. 2008;1(1):41–50.

[3] Biruk-Masrie Z, Nigussie-Dechassa R, Alemayehu Y, Abebie B, Tana T. Influence of treatment of seed potato tubers with plant crude essential oil extracts on performance of the crop. Afr Crop Sci J. 2015;23(3):295–304.

[4] Mediouni R, Mokrani K, Tarchoun N. Impact of the length of the storage period on physiological age and crop performance of four contrasting potato varieties (*Solanum tuberosum* L.) grown in a Mediterranean environment. Plant Physiol Rep. 2020;25(1):496–508.

[5] Oliveira JS, Moot DJ, Brown HE. Seed potato physiological age and crop establishment. Agron N Zealand. 2014;44:85–93.

[6] Caldiz DO. Physiological age research during the second half of the twentieth century. Potato Res. 2009;52:295–304.

[7] Delaplace P, Brostaux Y, Fauconnier M, Jardin PD. Potato (*Solanum tuberosum* L.) tuber physiological age index is a valid reference frame in postharvest ageing studies. Postharvest Biol Technol. 2008;50:103–6.

[8] Oliveira JS. Growth and development of potato (*Solanum tuberosum* L.) crops after cool season storage. PhD Thesis. New Zealand: Lincoln University Canterbury; 2015. p. 321.
[9] Struik PC, Wiersema SG. Seed potato technology. Wageningen: Wageningen Pears; 1999. p. 383.
[10] Reust W. EAPR working group physiological age of the potato. Potato Res. 1986;29(2):268–71.
[11] Wiersema SG. Physiological development of potato seed tubers. Lima, Peru: Technical Information Bulletin International Potato Center (CIP); 1985. p. 16.
[12] Wohleb CH. Why physiological age of potato seed tubers count. American vegetables grower; 2018.
[13] Alexopoulos AA, Aivalakis G, Akoumianakisa KA, Passam HC. Effect of gibberellic acid on the duration of dormancy of potato tubers produced by plants derived from true potato seed. Postharvest Biol Technol. 2008;49(3):424–30.
[14] Rykaczewska K. Assessment of potato mother tuber vigor using the method of accelerated ageing. Plant Prod Sci. 2013; 16(2):171–82.
[15] Beukema HP, van der Zaag DE. Introduction to potato production. Wageningen Netherlands: Pudoc. 1990; p. 208.
[16] Knowles NR, Zommick DH, Knowles LO, Blauer JM, Herman DJ, Parek MJ. How does in-season heat affect post-harvest physiology and quality? Washington Oregon Potato Conference Proceedings 2014, United States.
[17] Van der Zaag DE, Van Loon CD. Effect of physiological age on growth vigour of seed potatoes of two cultivars. 5. Review of literature and integration of some experimental results. Potato Res. 1987;30:451–72.
[18] Van Ittersum MK. Dormancy and growth vigour of seed potatoes. PhD Thesis. Wageningen, The Netherland: Wageninger University; 1992.
[19] Dimante I, Gaile Z. Assessment of potato plant development from mini tubers. Agron Res. 2018;16(4):1630–41.
[20] Struik PC, Haverkort AJ, Vrengdenhil O, Bus CB, Dankert R. Manipulation of tuber size distribution of a potato crop. Potato Res. 1990;33:417–32.
[21] Struik PC, Vrengdenhil D, Haverkort AJ, Bus CB, Dankert R. Possible mechanisms of size hierarchy among tubers on one stem of a potato (*Solanum tuberosum* L.) plant. Plant Res. 1991;34:187–203.
[22] Ifenkwe OP. Development of potato production in Nigeria. Nigeria-Netherlands workshop paper "Towards increased potato production in Nigeria, Vom, Plateau state, Nigeria; February 20–21, 1986.
[23] Okonkwo JC, Ifenkwe OP, Nwokocha HN, Knipers H. Possibilities of overcoming the limiting factors for potato production in Nigeria. III varieties and seed potato availability. In Towards increased potato production in Nigeria, Nigerian Netherlands workshop papers; 1986. p. 45–9.
[24] Deshi KE, Odiaka NI, Obasi MO. Physiological ageing of potato seed tubers as affected by storage conditions and storage duration in Plateau State, Nigeria. Acta Horticul. 2018;1225:247–54.
[25] Johnson A. Trails of Mercuric Chloride for the prevention of potato sickness. Annu Appl Biol. 2008;2391:153–64.
[26] Van Loon CD. Effect of physiological age on growth vigour of seed potatoes of two cultivars. 4. Influence of storage period and storage temperature on growth and yield in the field. Potato Res. 1987;30:441–50.
[27] Moll A. Einfluss der physiologischen Alterung bei pflanzknollen verschiedener sorten auf wachstum charakteristika im laborversuch. Potato Res. 1994;37:11–20.
[28] Mokrani K, Saadaoui W, Mediouni R, Tarchoun N. Agro-morphologic variations among eleven potato (*Solanum tuberosum* L.) cultivars. Afr J Agric Res. 2017;12(47):3355–65.
[29] Vakis NJ. Influence of physiological ageing of seed potatoes on yield and earliness. Potato Res. 1986;29:417–25.
[30] Taylor CE. The vegetative development of the potato plant. Ann Appl Biol. 1953;40:778–88.
[31] Iritani WM. Factors affecting physiological ageing (degeneration of potato tubers used as seed). Am Potato J. 1968;45(3):111–6.
[32] Oliveira JS, Brown HE, Moot DJ. Assessing potato canopy growth and development at the individual leaf level to improve the understanding of the plant source-sink relations. N Zeal J Crop Horticul Sci. 2021;49(295):325–46.
[33] Bremner PM, Radley RW. Studies in Potato Agronomy II. The effects of variety and time of planting on growth, development and yield. J Agric Sci. 1966;66:253–62.
[34] Razzaque MA, Ali MA. Effect of mulching material on the yield and quality of potato varieties under no tillage condition of Ganges tidal flood plain soil. Bangladesh J Sci Ind Res. 2009;44(1):51–6.
[35] Gao Y, Jia L, Hu B, Alva A, Fan M. Potato Stolon and Tuber Growth Influenced by Nitrogen Form. Plant Prod Sci. 2014;17(2):138–43.
[36] Johansen TJ, Lund L, Nolsen J. Influence of daylength and temperature during formation of seed potatoes on subsequent growth and yields under long day conditions. Potato Res. 2002;45:139–43.
[37] Johansen TJ, Nolsen J. Influence of low growth temperatures on physiological age of seed potatoes. Acta Agric Scan Sect B – Soil Plant Sci. 2004;54:185–8.
[38] Tessema L, Mohammed W, Abebe T. Evaluation of potato (*Solanum tuberosum* L.) varieties for yield and some agronomic traits. Open Agric. 2020;5:63–74.
[39] Caldiz DO, Brocchi G, Alamiz JR, Marchan L. Effects of the physiological age of seed potatoes on tuber initiation and starch and dry matter accumulation. PesqAgropBrasileira. 1996;31:853–6.
[40] Toosey RD. The influence of sprout development at planting on subsequent growth and yield. "*The growth of the Potato*". Proceedings of 10th Easter School. In Agricultural Science University of Nottingham. ed. Ivins JD and Milthorpe FL. London Butterworth, 1963.
[41] Bohl WH, Nolte P, Kleinkopf GE, Thornton MK. Potato seed management: Seed size and age. Univ Idaho Extension CIS 1031; 1995.
[42] Mannaf MA, Masood A, Siddique MA, Jahiruddin M, Faruq G, Motior MR. Influences of weight and row width of tubers from true potato seed. Bangladesh: Agricultural Research station; 2012.

Appendix

Table 1: Weekly temperature and relative humidity in ACS, DLS, and RTS during the 2010 (Sep–Dec) to 2011 (Jan–May) season in Jos

Year	Month/date	ACS			DLS			RTS		
		Temperature (°C)		RH	Temperature (°C)		RH	Temperature (°C)		RH
		Min	Max	%	Min	Max	%	Min	Max	%
2010	09/04	16.14	16.74	98.31	19.91	21.00	90.86	20.40	23.07	89.32
	09/11	15.46	15.59	97.77	20.17	21.93	92.04	21.48	25.70	82.94
	09/19	15.53	15.94	96.54	20.40	22.13	91.99	22.21	26.39	77.47
	09/26	15.44	15.61	95.56	20.17	22.84	91.63	21.87	26.09	71.81
	10/03	15.31	16.13	91.89	20.54	22.90	89.31	22.70	25.86	69.99
	10/10	15.53	16.74	92.21	20.81	22.66	89.43	21.27	24.29	79.31
	10/17	15.61	16.23	88.34	21.46	22.06	89.10	20.56	23.19	89.93
	10/24	15.50	16.13	87.14	22.10	21.84	86.46	20.06	23.79	89.69
	10/31	15.27	15.63	86.94	21.06	21.84	86.74	19.99	23.34	84.33
	11/07	15.33	15.77	82.09	20.29	22.46	72.83	20.43	23.76	75.86
	11/14	15.67	17.77	74.80	20.59	23.46	65.24	21.43	25.33	71.64
	11/21	15.49	21.46	70.31	19.64	23.04	58.69	20.99	23.91	61.14
	11/28	15.37	20.56	67.74	19.37	22.99	42.70	20.47	24.74	51.56
	12/05	15.37	21.27	64.94	19.40	23.07	37.81	20.46	24.71	45.97
	12/12	15.09	19.67	57.53	17.91	20.76	31.00	17.90	23.07	42.26
	12/19	15.11	21.17	62.66	18.04	22.29	31.81	19.36	23.47	40.51
	12/26	15.01	18.83	57.60	17.47	21.40	23.87	18.30	23.30	35.69
2011	01/02	15.06	18.26	57.80	16.56	20.33	30.10	17.30	21.84	39.31
	01/09	15.13	18.36	55.84	16.86	19.81	30.49	17.07	22.33	36.69
	01/16	15.39	18.90	44.46	15.14	19.39	27.50	15.70	21.76	33.44
	01/23	14.20	18.89	45.80	15.14	19.74	27.34	16.14	20.97	36.66
	01/30	16.00	22.19	45.81	18.66	23.31	22.01	20.03	25.23	26.80
	02/06	16.60	24.19	53.06	21.53	24.69	28.01	22.20	27.21	38.24
	02/13	15.64	22.19	55.59	21.04	23.94	33.13	21.27	25.70	35.37
	02/20	15.59	22.99	51.37	22.90	25.49	39.24	23.16	27.30	39.74
	02/27	15.51	18.76	53.83	23.11	24.39	40.80	22.49	27.24	41.53
	03/06	15.86	21.91	46.99	21.79	25.30	32.91	23.09	26.39	33.47
	03/13	16.24	22.96	43.93	23.31	26.71	25.09	24.01	28.99	23.56
	03/20	16.61	22.06	44.56	22.40	25.91	20.19	23.64	28.69	27.16
	03/27	15.93	22.97	44.57	24.93	26.73	46.24	24.63	28.63	37.33
	04/03	16.20	22.63	40.39	23.04	27.11	23.37	24.37	28.54	26.54
	04/10	16.36	22.80	40.83	24.37	26.37	24.97	23.73	28.31	21.49
	04/17	16.34	23.10	45.89	25.20	28.04	31.50	25.24	29.04	41.73
	04/24	16.19	23.97	48.67	28.09	27.69	49.79	25.29	31.57	59.27
	05/01	15.97	18.39	74.49	27.19	23.34	57.27	21.27	29.99	74.63
	05/08	15.47	19.99	69.79	26.16	23.99	64.36	22.14	29.44	78.79
	05/15	15.70	19.91	71.29	25.60	23.29	67.70	21.10	29.14	79.36
	05/22	16.30	20.60	72.96	26.20	24.24	65.59	22.53	29.50	78.84
	05/29	16.80	20.76	75.91	25.39	22.00	68.81	20.69	28.47	84.16

ACS, air-conditioned store; RTS, room temperature store; DLS, diffused light store; RH, relative humidity; min, minimum; and max, maximum.

Table 2: Weekly maximum and minimum air temperature and relative humidity in various potato stores in 2012 (Sep–Dec) to 2013 (Jan–May) season

Year	Month/date	ACS			DLS			RTS		
		Temperature (°C)		RH	Temperature (°C)		RH	Temperature (°C)		RH
		Min	Max	%	Min	Max	%	Min	Max	%
2012	09/16	17.10	20.76	98.03	20.56	23.26	87.67	19.67	21.49	94.61
	09/23	15.11	19.16	97.39	19.07	20.33	94.33	19.46	21.39	94.56
	09/30	14.26	16.89	95.86	20.10	21.56	92.24	21.07	23.06	91.47
	10/07	14.00	16.50	93.06	21.01	22.61	89.86	21.16	23.71	88.17
	10/14	13.94	16.73	90.14	20.97	22.86	87.73	22.00	24.24	84.20
	10/21	14.21	17.11	86.29	21.74	23.13	85.61	22.17	24.26	83.80
	10/28	14.74	16.70	87.61	21.57	22.76	85.27	21.53	23.80	81.51
	11/04	14.59	18.81	83.47	21.53	22.99	82.90	22.84	25.40	75.57
	11/11	14.94	19.64	75.60	21.93	23.67	74.31	22.37	25.04	65.94
	11/18	14.93	18.00	65.73	21.44	23.43	54.10	22.71	26.11	55.24
	11/25	15.49	18.00	67.24	21.96	24.26	48.94	23.31	26.31	50.86
	12/02	15.76	20.66	63.44	22.01	23.94	38.16	22.79	25.99	47.54
	12/09	16.86	21.56	60.63	21.83	23.84	43.36	23.13	26.26	44.40
	12/16	16.54	19.16	52.10	21.56	23.53	39.91	21.41	24.97	33.64
	12/23	16.33	20.59	39.51	19.99	22.10	27.89	20.01	23.74	31.60
	12/30	14.67	17.97	44.59	18.69	21.01	28.09	19.37	23.20	32.30
2013	01/06	15.01	18.71	45.50	17.69	20.16	28.51	19.66	23.61	35.19
	01/13	15.44	19.14	46.36	18.79	21.26	33.50	19.06	23.29	33.97
	01/20	15.43	18.19	50.87	18.64	21.54	29.67	22.66	25.93	37.27
	01/27	15.93	22.41	58.93	22.16	24.06	40.54	24.34	27.01	41.83
	02/03	14.96	19.01	41.66	22.30	23.99	46.23	19.71	23.37	32.84
	02/10	15.64	18.39	44.94	18.57	21.11	32.66	22.09	25.71	28.14
	02/17	15.80	19.64	44.33	21.21	24.09	21.40	24.03	27.23	26.50
	02/24	16.46	20.24	44.00	22.43	25.20	22.31	24.99	28.43	25.60
	03/03	17.44	23.26	43.16	24.47	27.03	25.59	26.59	29.63	25.94
	03/10	16.80	22.70	48.06	25.99	28.26	37.16	27.21	29.73	35.63
	03/17	16.99	23.26	47.84	25.61	27.70	53.46	26.80	29.04	35.74
	03/24	16.47	23.56	50.91	25.63	27.90	42.59	26.44	28.94	37.06
	03/31	15.59	18.66	66.67	25.34	27.00	60.64	24.81	27.04	54.63
	04/07	15.36	18.29	65.91	23.90	25.59	63.97	25.06	26.99	59.73
	04/14	16.17	20.16	69.19	24.10	25.60	70.91	24.10	26.56	62.13
	04/21	15.94	18.61	72.37	24.10	25.76	69.36	23.06	24.94	68.44
	04/28	15.93	17.96	75.10	22.04	23.49	80.44	22.10	24.50	72.77
	05/05	17.23	22.74	72.31	22.89	24.71	79.86	23.44	25.39	75.79
	05/11	17.80	22.19	74.06	23.13	24.50	83.07	21.79	24.00	82.83
	05/18	17.10	20.76	98.03	21.89	23.83	85.91	22.34	24.76	81.63
	05/25	15.11	19.16	97.39	22.77	24.51	83.77	22.90	25.11	80.24

ACS, air-conditioned store; RTS, room temperature store; DLS, diffused light store; RH, relative humidity; min, minimum; and max, maximum.