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Postharvest application of growth regulators on *Dioscorea alata* (L.) and *Dioscorea rotundata* (Poir.)

Aplicación de reguladores de crecimiento en *Dioscorea alata* (L.) y *Dioscorea rotundata* (Poir.) durante la postcosecha

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***Dioscorea alata* L.**

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ABSTRACT

Yam is a tuber that sees high demand and consumption in Colombia, whose post-harvest quality losses during storage have been a challenge for farmers. At the Universidad de Cordoba-Colombia, Agronomy Engineering program, between March and August of 2019, a trial was established to estimate the effect of two growth regulators on the variables: tuber weight loss (TWL), tuber sprouting (TS), starch on a dry basis (SD), and reducing sugars (RS) during storage for 120 days, with evaluations every 30 days. A completely randomized design with a 4×2 factorial arrangement plus two additional treatments with three replications was used. Four concentrations of abscisic acid (ABA) were tested: 0, 10, 15, and 20 mg L^{-1} in the species *D. alata* and *D. rotundata*, plus paclobutrazol (PBZ): 15 mL kg^{-1}, for a total of 10 treatments. Each experiment unit consisted of 12 tubers that were preserved in darkness at 23°C and 53% relative humidity on average. ABA and PBZ exerted effective control over the sprouting and weight loss of the tubers during the first 90 days of storage in both species, which averaged 24.4%, i.e. approximately 488 g, favoring high starch contents, and did not influence the reducing sugar content.

Additional key words: abscisic acid; paclobutrazol; tuber; yam; starch; reducing sugars.

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RESUMEN

El ñame es un tubérculo de alta demanda y consumo en Colombia, cuyas pérdidas de calidad poscosecha durante el almacenamiento han sido un reto para los agricultores. En la Universidad de Córdoba-Colombia, en el programa de Ingeniería Agronómica, entre marzo y junio de 2019, se estableció un ensayo para estimar el efecto de dos reguladores de crecimiento sobre las variables: pérdida de peso de los tubérculos (PPT), brotación de tubérculos (BT), almidón en base seca (AS) y azúcares reductores (AR), durante el almacenamiento por 120 días, con evaluaciones cada 30 días. Se utilizó un diseño completamente aleatorizado con arreglo factorial 4×2 más dos tratamientos adicionales, con tres repeticiones. Se probaron cuatro concentraciones de ácido abscísico (ABA): 0, 10, 15 y 20 mg L^{-1} en las especies *D. alata* y *D. rotundata*, más paclobutrazol (PBZ): 15 mL kg^{-1}, para un total de 10 tratamientos. Cada unidad experimental estuvo conformada por 12 tubérculos, conservados bajo oscuridad, a 23°C y 53% de humedad relativa, en promedio. El ABA y el PBZ ejercieron control efectivo sobre la brotación y la pérdida de peso de los tubérculos durante los primeros 90 días de almacenamiento en ambas especies, que en promedio fue del 24.4%, es decir, 488 g, aproximadamente, favorecieron la conservación de altos contenidos de almidón y no influyeron en el contenido de azucares reductores.

Palabras clave adicionales: ácido abscísico; paclobutrazol; tubérculo; ñame; almidón; azúcares reductores.

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INTRODUCTION

Global yam production is estimated at more than 253.5 million tons, with more than 7.4 million hectares established annually, and yams are ranked fourth in importance worldwide among plant roots and tubers (Borges *et al*., 2011). Colombia is the third-largest producer in the Americas and one of the main yam exporting countries to the United States, with a yield of 10.05 t ha^{-1} planted and a total of 108,067 ha planted in 2014 (Pérez and Campo, 2016). This yield is due to factors within the production process, such as the type of seed, soil and planting techniques (Acevedo *et al.*, 2015).

Greater production is seen in the departments of Bolivar, Cordoba and Sucre (Álvarez, 2000), where at least 20,000 families are dedicated this crop (Doncel and Pérez-Cordero, 2017) and where the diet of the inhabitants relies on yams because the main component is starch, which contains high amounts of carbohydrates (Pinzon *et al*., 2013).

Additionally, the pharmaceutical industry uses this tuber (*Dioscorea*) for the treatment of diabetes, dysmenorrhea, and inflammation, etc., (Ramos *et al*., 2015).

The following species are cultivated: creole yam (*D. alata* L.), hawthorn yam (*Dioscorea rotundata* Poir), papo yam (*Dioscorea bulbífera*), sugar yam (*Dioscorea esculenta*) and *ñampin* (*Dioscorea trifida*), among more than 100 species of the genus *Dioscorea*; *D. alata* L. and *D. rotundata* Poir., stored by farmers for four months on average before commercialization, which directly affects quality and causes a significant amount of tubers to deteriorate (Dramani, 2013) because of a lack of adequate storage, packaging, and logistics, with vulnerability to physiological and pathological factors that affect the income of producers (Tanye, 2016).

During storage, transpiration and respiration cause desiccation and weight loss, aggravated by the sprouting process, which is characterized by a decrease in the starch content and an increase in reducing sugars, which make consumption and marketing unacceptable, generating losses for producers (Afoakwa and Sefa-Dedeh, 2001).

Losses under normal storage conditions can reach up to 10% after three months and 25% after five months (Osunde and Orhevba, 2009). To counteract this, tuber dormancy must be maintained, for which growth-inhibiting substances are needed (Hamadina, 2011). Abscisic acid (ABA) seems to control dormancy through the tuberization process, and it has been suggested that both ABA and paclobutrazol (PBZ) protect against water loss (Rodríguez *et al*., 2000).

Technological alternatives that help reduce weight loss in yam tubers and reduce sprouting must be tested. Therefore, the purpose of this study was to evaluate ABA and PBZ as treatments to reduce postharvest losses during tuber storage and estimate which concentrations of the exogenous applications saw better responses for prolonged storage of yams under optimal conditions, favoring commercialization as a product with excellent quality in the market.

MATERIALS AND METHODS

Location

This test was carried out in the Plant Physiology laboratory at the Universidad de Cordoba, in Monteria (Colombia), with the geographic coordinates 8º 48" latitude N and 75º 52" longitude W and an altitude of 13 m a.s.l., from March to August of 2019.

Experiment material

Tubers of the species *Dioscorea alata* L. and *Dioscorea rotundata* Poir., were selected, with an average weight per unit of 2.0 kg, without signs of sprouting, in good phytosanitary condition, and without mechanical damage. The total weight of the tubers was 720 kg.

Experiment design

The treatment structure consisted of four concentrations of abscisic acid (ABA): 0, 10, 15, and 20 mg L^{-1} applied to the yam species *D. alata* and *D. rotundata*, plus paclobutrazol (PBZ): 15 mL kg^{-1} also applied to each species (as two additional treatments), for a total of 10 treatments. The study was developed under a completely randomized design with a 4×2 factorial arrangement plus two additional treatments, with three repetitions. Each experiment unit consisted of 12 tubers that were placed, labeled and randomized according to the design structure on pallets in a warehouse in complete darkness at 23°C and 53% relative humidity on average. At 30 d, the first reading of the variables was taken, every 30 d thereafter until day 12.

Response variables

Tuber weight loss (TWL): estimated with the difference between the initial weight and the final weight, in grams, of the tubers at 30, 60, 90, and 120 d of storage with a precision balance with an approximation of 0.01 g. Tuber sprouting (TS): estimated as the average percentage of sprouts per treatment, based on the number of sprouts accumulated weekly per tuber and per experiment unit. To determine the Starch on a dry basis (SD) and reducing sugars (RS): tubers were sampled during the established periods of the study: 30, 60, 90 and 120 d of storage. The selected tubers were washed with distilled water, sliced, and then subjected to drying in an oven at 50°C for 2 d. The dried samples were then ground in an industrial mill. The percentages of starch and reducing sugars were determined with the DNS method (Salcedo *et al*., 2017). Initially, a calibration curve was made in a spectrophotometer using the DNS method, varying the concentration of glucose solutions to obtain absorbance values with a linear correlation of 99.95%. To determine the starch content of the samples, they were subjected to enzymatic hydrolysis to a dispersion of yam flour in an aqueous medium consisting of a dextrinization or partial hydrolysis stage and a saccharification or total hydrolysis stage.

Dextrinization stage. Two hundred mg of the sample were weighed, to which 42 mL of distilled water were added; then, 20 μL of the α-amylase solution were added. Afterwards, a thermostat bath at a temperature between 80-90°C was used for 15 min with constant agitation, which was allowed to cool, and the lugol test was performed to verify that the starch had been completely dextrinized (negative lugol test). The saccharification stage was then carried out.

Saccharification stage. To the dextrinized sample, 2.5 mL of sodium acetate-acetic acid buffer solution (0.1M; pH 4.8) and 300 μL of amyloglucosidase solution were added for use in a thermostatted bath at a temperature of 60°C for 30 min with constant agitation. The hydrolyzed sample was cooled to room temperature, and two drops of 2.0 N sodium hydroxide (NaOH) solution were added to neutralize the sample, which was transferred to a 125 mL erlenmeyer by filtering the solution with absorbent cotton and adding distilled water until a volume of 125 mL was reached. Finally, the concentration of reducing sugars (CAR) was determined using the DNS method.

Statistical and data analysis

The data were subjected to analysis of variance (ANOVA) using the Statistical Analysis Software package (SAS, 1993). The mean squares of the variables tuber weight loss (TWL), tuber sprouting (BT), flour dry basis (HS) and reducing sugars (RS) of tubers of *D. alata* and *D. rotundata* species at 30, 60 and 90 d of storage were analyzed. In addition, the simple effects of the ABA and PBZ levels on the variables during the same period were estimated for both species.

RESULTS AND DISCUSSION

The analysis of variance showed highly significant differences between the species ($P<0.01$) for tuber weight loss (TWL) during 90 and 120 d of storage after applying ABA, while, at 30 and 60 d, there were no differences. Likewise, the ABA concentrations and the Species×ABA interaction were significant at 30, 60, and 90 d. The additional treatments with PBZ, when contrasted with the factorial part, were only significant at 90 d. The contrast between the two species treated with PBZ showed significant differences at 30, 60, 90, and 120 d (Tab. 1).

In *D. alata*, the lowest TWL was recorded with ABA concentrations of 10 and 15 mg L^{-1} at 30 d. At 60 d, there were no differences between the ABA levels, and the PBZ did not have an influence. At 90 d, the lowest TWL was registered with the ABA at 10, 15, and 20 mg L^{-1}, overcoming the effect of PBZ and the non-application of ABA. At 120 d, there were no differences in the TWL with any of the concentrations for the two growth regulators. In *D. rotundata*, the lowest TWL were recorded with 10 mg L^{-1} of ABA at 30, 60, and 90 d, and at 30 and 90 d with the PBZ. As in *D. alata*, at 120 d, there were no differences in the TWL with any of the concentrations for both growth regulators (Tab. 2).

The applications of ABA and PBZ decreased the TWL in both species in the periods over three months. In both species, a gradual decrease in the TWL was observed between 30 and 120 d of storage, 24.4% on average. These results corroborate the report by Dramani (2013), who indicated that yams can lose about 20% of their weight after three months and reach 50 to 80% weight loss after six months of storage, depending on the species. These losses are due to the decrease in substrates as a result of respiration and loss of water from transpiration, reducing the quality of products in terms of appearance, freshness, nutritional content, and loss of antioxidants (Rodríguez *et al*., 2006).

Table 1. Mean squares of the analysis of variance of tuber weight loss (TWL), tuber sprouting (TS), starch on a dry basis (SD) and reducing sugars (RS) of the species *D. alata* and *D. rotundata* after 30, 60 and 90 days of storage (initial average tuber weight: 2 kg).

RV	ST	Sp.	ABA	Sp.×ABA	C1	C2
TWL	30	29610.4^{NS}	113317.4**	48148.8*	1848.7^{NS}	287766.0**
	60	60.9^{NS}	232224.6**	161550.4**	37089.6^{NS}	554088.7**
	90	3080896.6**	450660.4**	337010.3**	459174.4**	719680.7**
	120	3145881.3**	325292.1^{NS}	119483.6^{NS}	221278.4^{NS}	1346160.7**
TS	30	27.5**	905.1**	165.6**	8.9**	316.8**
	60	321.3**	779.5**	51.9**	174.29	298.2**
	90	8.2**	269.2**	177.3**	416.5**	187.0**
	120	3145881.3**	325292.1^{NS}	119483.6^{NS}	221278.4^{NS}	1346160.7**
SD	30	7.3^{NS}	258.9**	230.3**	0.58^{NS}	496.5**
	60	72.0*	116.9**	133.7**	0.0087^{NS}	332.0**
	90	178.7**	96.7**	105.3**	0.06^{NS}	262.0**
	120	784.8**	247.5**	82.6**	2.94^{NS}	71.2*
RS	30	0.0003^{NS}	0.048**	0.033*	0.0007^{NS}	0.17**
	60	0.08**	0.03**	0.02*	0.003^{NS}	0.123**
	90	0.31**	0.08**	0.023**	0.012^{NS}	0.062**
	120	1.37**	0.30**	0.063**	0.006^{NS}	0.007^{NS}

RV: response variable; ST: storage time (d); sp: species; C1: Contrast (Factorial *vs.* (PBZ-*D. Alata*, PBZ-*D. Rotundata*); C2: Contrast (PBZ *D. alata* vs PBZ *D. rotundata*); ABA: abscisic acid; PBZ: Paclobutrazol; ^{NS}: not significant, *: significant at 5% and **: significant at 1%, according to the Snedecor F test.

The reduction in tuber size and weight during storage could be explained by the use of carbohydrate reserves for respiration, accompanied by transpiration, since some products present greater cell disintegration and weak cell walls and membranes during storage, allowing water to escape through transpiration at a high rate (Kays, 2004).

ABA and PBZ have been suggested for protection against water loss; yam plants treated with PBZ showed greater resistance to desiccation than untreated plants (Rodríguez, 2000). A similar result was reported by Pantoja (2015) in potatoes (*Solanum phureja*). In *D alata*, the lowest tuber sprouting (TS) was obtained with 20 mg L^{-1} of ABA at 30 and 90 d, and with 15 mg L^{-1} of PBZ at 60 d, with percentage differences concerning the non-application of ABA, 33.2, 28.1, and 21.1% (Tab. 3). This indicates that both growth regulators exerted effective control over ST during the first 90 d.

At 120 d, with all ABA and PBZ concentrations, 100% TS was reached in both species, indicating a decreasing loss of sprouting control over time. In *D. rotundata*, the lowest sprouting was estimated with 15 mg L^{-1} of ABA at 30 and 60 d, and with PBZ at 90 d of storage, with percentage differences of 28.1, 28.2, and 24.5%, respectively, as compared with no ABA application.

These results could be explained in terms of the relationship between the growth-inhibiting substances and the dormancy state of the tubers. Hormones such as abscisic acid (ABA), gibberellins (GAs), ethylene, and cytokinins (CKs) are present in the dormancy period. Suttle (2004) pointed out that both ABA and ethylene are necessary for the initiation of tuber dormancy but only ABA maintains the latent state because it is involved in the inhibition of DNA and RNA synthesis, while GAs are involved in the acceleration of DNA and RNA synthesis, that is, while GAs promotes shoot growth, ABA maintains latency.

In this experiment, the ABA and PBZ, at the concentrations used, slowed down the ST process for up to a storage period of no more than 90 d. However, the decreased ABA concentration at which sprouting starts must be known (Claassens and Vreugdenhil, 2000). When there are changes in the concentrations of GA and ABA, ABA biosynthesis appears to be involved in the induction and maintenance of tuber dormancy (Suttle, 2004).

However, authors such as Biemelt *et al.* (2000) disagreed, not having found a correlation between the ABA levels and sprouting during storage. This indicated that shoot growth requires the supply of carbohydrates obtained from soluble sugars or starch. Also, these authors suggested that studies should focus more on the mobilization and transport of sucrose than on phytoregulators to understand the sprouting process in tubers.

Villar (2015) stated that the delay in sprouting that is achieved with regulators such as ABA can be related only to the time necessary for the tuber to metabolize the extra dose of circulating ABA, and that subsequent attempts at maintaining high concentrations of this hormone for dormancy are not effective.

Table 2. Simple effects of ABA and PBZ levels on tuber weight loss (TWL) at 30, 60, and 90 days of storage (DS) in the two yam species.

DS	Species	ABA (mg L^{-1})				PBZ (mg L^{-1})	General means
		0	10	15	20	15	
30	*D. alata*	3,446.7±2.0 a	3,252±64.9 b	3,181.3±45.3 b	3,465±53.2 a	3,610.0±7.3 aA	3,391.0±34.5 A
	D. rotundata	3,518.7±36.8 a	3,131.3±97.2 b	3,491.0±74.5 a	3,485.0±106.9 a	3,175.0±53.2 bB	3,359.6±73.7 A
60	*D. alata*	3,190.7±108.9 a	3,038±64.9 a	2,971.3±45.3 a	3,275±53.2 a	3,358.0±118.2 aA	3,166.6±78.1 A
	D. rotundata	3,002.7±36.8 a	2,297.3±97.2 b	3,007.7±74.5 a	2,947±106.9 a	2,750.2 ±54.6 aB	2,801.0±74.0 B
90	*D. alata*	3,153.0±2.1 a	2,824±64.9 b	2,760.3 ±45.3 b	3,084 ±53.2 b	3,232.0±174.4 aA	3,010.6±68.0 A
	D. rotundata	2496.3 ±42.7 a	1,463.3 ±97.2 b	2,521.0±74.5 a	2,309±56.7 a	2,539.3±58.7 bB	2,265.8±66.0 B
120	*D. alata*	3,153±31.0 a	2,823.7±97.7 a	2,759.7±52.8 a	3,083.7±44.3 a	2,854.0±343.1 aA	2,934.8±113.8 A
	D. rotundata	2,601±26.1 a	1,735±263.7 a	2,184.3±377.0 a	2,420.0±152.9 a	1,906.7±76.5 aB	2,169.4±179.2 B

Means plus standard errors with the same lowercase letters do not differ significantly according to the Tukey test ($P\leq0.05$), horizontal comparison for ABA and PBZ; vertical comparison of the two species for PBZ and General means in capital letters.

For the effect of PBZ, a decrease of up to 50% in length and number of shots of potato tubers stored and treated with PBZ was reported (Cheema, 2010). Likewise, it has been found that periodic applications of PBZ at low concentrations favor the accumulation of starch, with a tendency to increase the number of tubers (Flores *et al*. 2016).

Pantoja (2015), on the other hand, warned about the efficient behavior of PBZ in the regulation of sprouting *Solanum phureja* tubers, reporting sprouting percentages lower than 3.33% for treatments with doses of 30 mL kg^{-1} under unspecialized storage conditions, up to 9 d, with 98% of the tubers without the presence of shoots, which may be due to the maintenance of low levels of GAs that are involved in the growth of shoots because PBZ inhibits GA biosynthesis (Hartmann *et al*., 2011). Similar results have been found with PBZ foliar sprays on potatoes, delaying the appearance of new plants and the beginning of tuberization (Kianmehr *et al*., 2012; de Araújo *et al*., 2020).

Contrary effects have been reported in the date palm (*Phoenix dactylifera* L.), with an increase and multiplication of shoots (Awadh *et al*., 2019), which could indicate that the action of PBZ will not only depend on the concentration used but on the studied species, the form of application, the absorption and the phenological stage in which the application was made (Mabvongwe *et al*., 2016).

The starch percentages on a dry basis (SD) in *D. alata* were higher with 10 and 20 mg L^{-1} of ABA at 30, 60, and 90 d of storage, while, in *D. rotundata*, there were no differences between the different concentrations of growth regulators at 30 and 60 d; however, at 90 d, the highest SDs were obtained with 15 and 20 mg L^{-1} of ABA and 15 mg L^{-1} of PBZ. Likewise, *D. rotundata* always presented a higher starch content during the entire storage period (Tab. 4).

These results indicate that the ABA and PBZ favored the preservation of a high SD content in both species, thereby increasing its importance as a food ingredient of great energy value and as a possible alternative source of commercial starch (Techeira, 2008). The SD percentage in both species fluctuated between 73.7 and 80.5% for *D. alata* and 80.8-83.2% for *D. rotundata* in the first 90 d, similar to the report by Techeira (2008) for *D. alata*.

Plant treatments with PBZ have caused an increase in the number of enzymes such as starch synthase responsible for the biosynthesis of starch, increasing its content in tubers (Mabvongwe *et al*., 2016). However, other authors have pointed out that the percentages of starch in tubers may decrease when treated with growth regulators such as PBZ, which could be due to a momentary dilution of the starch content as the result of an increase in the water content of tubers, depending on the conditions in which they are maintained (Araujo *et al*., 2020) or the presence of a high GA content that prevents the accumulation of starch in tubers (Mabvongwe *et al*., 2016).

The contents of reducing sugars (RS) in *D. alata* were not significantly different between the ABA levels during the first 90 d of storage but, at 120 d, the PBZ was higher(1.47%) with ABA at 20 mg L^{-1} (Tab. 5). For *D. rotundata*, the treatment with ABA at 10 mg L^{-1}

Table 3. Simple effects of ABA and PBZ levels on tuber sprouting (TS) at 30, 60, and 90 days of storage (DS) in the two yam species.

DS	Species	ABA (mg L^{-1})				PBZ (mg L^{-1})	General means
		0	10	15	20	15	
30	*D. alata*	75.1±0.3 a	58.1±0.1 b	50.0±0.0 b	41.9±0.2 c	51.4±0.7 bB	55.3±0.3 B
	D. rotundata	70.0±0.0 a	65.8±0.7 b	41.9±0.1 d	56.0±0.3 c	66.0±0.5 aA	59.9±0.3 A
60	*D. alata*	82.7±0.9 a	63.3±0.3 b	60.3±0.4 c	57.5±0.5 d	55.2±0.4 eB	63.8±0.5 B
	D. rotundata	85.5±0.3 a	72.2±0.6 b	57.5±0.3 d	67.3±0.1 c	69.3±0.2 aA	70.3±0.3 A
90	*D. alata*	91.0±0.4 a	70.0±0.0 c	76.7±0.4 b	89.4±0.2 a	78.3±0.1 bA	81.1±0.2 A
	D. rotundata	91.6±0.9 a	82.2±0.7 b	79.8±0.4 c	75.3 ±0.2 d	67.1±0.1eB	79.2±0.5 A
120	*D. alata*	100±0.0 a	100±0.0 a	100±0.0 a	100±0.0 a	100.0±0.0 aA	100.0±0.0 A
	D. rotundata	10±0.0 a	100±0.0 a	100±0.0 a	100±0.0 a	100.0±0.0 aA	100.0±0.0 A

Means with the same lowercase letters do not differ significantly according to the Tukey test ($P \leq 0.05$), horizontal comparison for ABA and PBZ, vertical comparison of the two species for PBZ and General means, in capital letters.

Table 4. Simple effects of ABA and PBZ levels on starch on a dry basis (SD) at 30, 60, and 90 days of storage (DS) in the two yam species.

DS	Species	ABA (mg L^{-1})				PBZ (mg L^{-1})	General means
		0	10	15	20	15	
30	*D. alata*	72.3±3.5 b	97.8±7.2 a	70.9±0.8 b	87.4±1.1 a	73.0±3.4 bB	80.5±3.2 B
	D. rotundata	78.4±0.8 a	81.5±1.7 a	83.0±1.6a	82.0±0.2 a	91.2±2.2 aA	83.2±1.3 A
60	*D. alata*	72.0±1.6 b	86.2±5.4 a	67.9±1.3 b	82.4±0.7 a	71.4±2.4 bB	76.0±2.3 B
	D. rotundata	77.6±0.7 a	77.4±1.4 a	82.1±2.1 a	84.7±0.4 a	86.3±1.2 aA	81.6±1.2 A
90	*D. alata*	71.3±0.8 abc	80.4±4.5 a	66.4±1.7 c	80.0±1.0 a	70.6±1.9 abcB	73.7±2.0 B
	D. rotundata	77.2±0.7ab	75.3±1.3 b	81.6±2.4 a	86.1±0.7 a	83.8±0.8 aA	80.8±1.2 A
120	*D. alata*	69.4±2.7 ab	63.1±1.8 ab	61.8±2.8 ab	72.6±2.4 a	68.6±0.3 abB	67.1±2.0 B
	D. rotundata	76.0±0.8 b	69.1±0.9 b	80.3±3.2 b	90.1±1.6 a	75.4±0.4 bA	78.2±1.4 A

Means with the same lowercase letters do not differ significantly according to the Tukey test ($P \leq 0.05$), horizontal comparison for ABA and PBZ, vertical comparison of the two species for PBZ and General means, in capital letters.

had a significant influence only at 90 and 120 d, expressed in a lower content of RS (1.23 and 1.05%, respectively), than in the other levels of ABA and PBZ.

These results indicate that the RS content was not related to the sprouting of tubers since the non-application of growth regulators was expected to influence a higher content of reducing sugars as the result of the interconversion of carbohydrates for the production of oxidizable substrates needed in cell division for the generation and growth of new shoots. For potatoes, Pantoja (2015) reported that growth inhibitors did not have a significant effect on the content of reducing sugars, always maintaining low concentrations both in tubers treated with inhibitors and in untreated ones.

For *Lilium rubellum*, Xu *et al*. (2006) reported an increase in the sugar content in tubers with the highest sprouting, related to the possible combined effect of a decrease in free ABA, the accumulation of sugars, and the decrease or increase of some factors unknown in bulbs. Likewise, El-Sherbiny *et al*. (2017) reported high percentages of total sugars in *Solanum tuberosum* L., similar to those detected by Mahto and Das (2014) in potato tubers.

Araujo (2020) reported a decrease in RS in potato tubers treated with PBZ. The accumulation of soluble sugars could be related to the release of endodormancia from the sprout, possibly by reducing the osmotic potential that triggers the events that lead to dormancy of the buds or sprouts in potatoes (Pantoja,

Table 5. Simple effects of the levels of ABA and PBZ on the content of reducing sugars (RS) at 30, 60, and 90 days of storage (DS) in the two yam species.

DS	Species	ABA (ml L^{-1})				PBZ (mg L^{-1})	General means
		0	10	15	20	15	
30	*D. alata*	1.26±0.07 b	1.59±0.14 a	1.26±0.01 b	1.47±0.02 b	1.21±0.06 bB	1.36±0.06 B
	D. rotundata	1.33±0.01 a	1.41±0.03 a	1.42±0.03 a	1.39±0.01 a	1.55±0.04 aA	1.42±0.02 A
60	*D. alata*	1.19±0.01 b	1.36±0.09 ab	1.18±0.03 b	1.38±0.02 ab	1.22±0.05 bB	1.27±0.04 B
	D. rotundata	1.33±0.02 b	1.32±0.02 b	1.43±0.04 ab	1.50±0.01 a	1.50±0.02 aA	1.42 ±0.02 A
90	*D. alata*	1.12±0.05 a	1.12±0.03 a	1.10±0.05 a	1.29±0.04 a	1.23±0.04 aB	1.15±0.04 B
	D. rotundata	1.33±0.03 b	1.23±0.02 c	1.43±0.06 ab	1.62±0.03 ab	1.43±0.02 abA	1.41±0.03 A
120	*D. alata*	0.87±0.06 b	0.71±0.03 bc	0.88±0.04 b	1.05±0.05 ab	1.21±0.01 aB	0.94±0.04 B
	D. rotundata	1.30±0.04 b	1.05±0.01 c	1.38±0.04 b	1.81±0.04 a	1.35±0.01 bA	1.38±0.03 A

Means with the same lowercase letters do not differ significantly according to the Tukey test ($P \leq 0.05$), horizontal comparison for ABA and PBZ, vertical comparison of the two species for PBZ and General means, in capital letters.

2015) and in dormant onion bulbs (Benkeblia *et al*., 2008). An increase in sugars is not only part of the nutrition that maintains growth but also signals control of sprout development (Chao and Serpe, 2010).

CONCLUSIONS

Abscisic acid (ABA) and paclobutrazol (PBZ) exercised effective control over sprouting and tuber weight loss during the first 90 d of storage in the yam species *D. alata* and *D. rotundata*, and their use is suggested as a management alternative to reduce losses in quantity and quality during post-harvest conservation.

The best results for sprouting reduction in both species were obtained with ABA concentrations of 20 and 15 mg L^{-1} of PBZ during the first 90 d, with percentages up to 33.2% in *D. alata* and 28.2% in *D. rotundata.* The lowest weight loss in both species was recorded with ABA concentrations of 10 and 15 mg L^{-1} during the first 90 d.

The ABA, at concentrations of 10, 15, and 20 mg L^{-1}, and PBZ, at 15 mg L^{-1}, favored the conservation of high starch contents in both species.

The applied concentrations of ABA and PBZ did not influence the content of reducing sugars. Only up to 90 and 120 d of storage, a decrease in reducing sugar content was observed in *D. rotundata* with concentrations of 10 mg L^{-1} of ABA.

Conflict of interests: The manuscript was prepared and reviewed by the three authors, who declare that there are no conflicts of interest that affect the validity of the research results.

BIBLIOGRAPHIC REFERENCES

Acevedo, A., J. Salcedo, and I. Sandoval. 2015. Desarrollo y productividad de ñame (*Dioscorea trifida* y *Dioscorea esculenta*) en diferentes condiciones hídricas. Acta Agron. 64(1), 30-35. Doi: 10.15446/acag.v64n1.43917

Afoakwa, E. and S. Sefa-Dedeh. 2001. Chemical composition and quality changes occurring in *Dioscorea dumetorum* pax tubers after harvest. Food Chem. 75(1), 85-91. Doi: 10.1016/S0308-8146(01)00191-1

Álvarez, A. 2000. Prácticas agronómicas para el cultivo del ñame. pp. 55-65. In: Guzmán, M. and G. Buitrago (eds.). Ñame: producción de semilla por biotecnología. Unibiblos, Universidad Nacional de Colombia, Bogota.

Araújo, F., M.N. Santos, N. Araújo, T. Silva, L. Costa, and F. Finger. 2020. Growth and dry matter partitioning in potatoes as influenced by paclobutrazol applied to seed tubers. Rev. Colomb. Cienc. Hortic. 14(1), 135-143. Doi: 10.17584/rcch.2020v14i1.10357

Awadh, H., M. Abdulhussein, and A. Almusawi. 2019. Effects of paclobutrazol and sucrose in date palm (*Phoenix dactylifera* L.) micropropagation via direct organogenesis. Plant Arch. 19(1), 1130-1134.

Benkeblia, N., A. Alexopoulos, and H. Passam. 2008. Physiological and biochemical regulation of dormancy and sprouting in potato tubers (*Solanum tuberosum* L.). Fruit Veg. Cereal Sci. Biotech. 2, 54-68.

Biemelt, S., M. Hajirezaei, E. Hentschel, and U. Sonnewald. 2000. Comparative analysis of abscisic acid content and starch degradation during storage of tubers harvested from different potato varieties. Potato Res. 43(4), 371-382. Doi: 10.1007/BF02360541

Borges, M., R. Destrade, S. Meneses, R. Gómez, B. Malaurie, P. Hamon, and L. Demenorval. 2011. Optimización de un medio de cultivo para plantas micropropagadas de *Dioscorea alata* L. Rev. Colomb. Biotecnol. 13(2), 221-228.

Chao, W.S. and M.D. Serpe. 2010. Changes in the expression of carbohydrate metabolism genes during three phases of bud dormancy in leafy spurge. Plant Mol. Biol. 73(1-2), 227-239. Doi: 10.1007/s11103-009-9568-9

Cheema, M.U.A. 2010. Dormancy and sprout control in root and tuber crops. PhD thesis. University of Greenwich, London.

Claassens, M.M.J. and D. Vreugdenhil. 2000. Is dormancy breaking of potato tubers the reverse of tuber initiation¿ Potato Res. 43(4), 347-369. Doi: 10.1007/BF02360540

Doncel, P. and A. Pérez-Cordero. 2017. *Burkholderia cepacia* aisladas de variedades de ñame con actividad antimicrobiana contra *Colletotrichum gloeosporioides*. Rev. Colomb. Cienc. Anim. 9(Suppl.), 31-38. Doi: 10.24188/recia.v9.nS.2017.518

Dramani, Y. 2013. Effect of postharvest waxing treatments, yam variety and tuber size on shelf life of white yam (*Dioscorea rotundata* Poir). PhD thesis. Universidad de Ghana-Legon, Accra, Ghana.

El-Sherbiny, S.M., M.E. Ragab, M.S. Abd-El-Moula, and E.A. Ragab. 2017. Minimizing postharvest losses in potato (*Solanum tuberosum* L.) tuber using gamma irradiation, mint oil and paclobutrazol under unrefrigerated storage condition. Arab. Univ. J. Agric. Sci. 25(1), 169-178. Doi: 10.21608/ajs.2017.13400

Flores-López, R., R. Martínez-Gutierrez, H. López-Delgado, and M. Marín-Casimiro. 2016. Aplicación periódica de bajas concentraciones de paclobutrazol y ácido salicílico en papa en invernadero. Rev. Mex. Cienc. Agríc. 7(5), 1143-1154. Doi: 10.29312/remexca.v7i5.238

Hamadina, E.I. 2011. The control of yam tuber dormancy: A framework for manipulation. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Hartmann, A., M. Senning, P. Hedden, U. Sonnewald, and S. Sonnewald. 2011. Reactivation of meristem activity and sprout growth in potato tubers require both cytokinin and gibberellin. Plant Physiol. 155(2), 776-796. Doi: 10.1104/pp.110.168252

Kays, S.J. and R.E. Paull. 2004. Postharvest biology. Exon Press, Athens, GA.

Kianmehr, B., M. Otroshy, M. Parsa, M. Mohallati, and K. Moradi. 2012. Effect of plant growth regulation during in vitro phase on potato minituber production. Intl. J. Agri. Crop Sci. 4(15), 1060-1067.

Mabvongwe, O., B.T. Manenji, M. Gwazane, and M. Chandiposha. 2016. The effect of paclobutrazol application time and variety on growth, yield, and quality of potato (*Solanum tuberosum* L.). Adv. Agric. 2016, 1585463. Doi: 10.1155/2016/1585463

Mahto, R. and M. Das. 2014. Effect of gamma irradiation on the physico-mechanical and Chemical properties of potato (*Solanum tuberosum* L.), cv. 'Kufri Sindhuri', in non-refrigerated storage conditions. Postharvest Biol. Technol. 92, 37-45. Doi: 10.1016/j.postharvbio.2014.01.011

Ortiz, L. and V. Flórez. 2008. Comparación cuantitativa de ácido abscísico y citoquininas en la tuberización de *Solanum tuberosum* L. y *Solanum phureja Juz*. et Buk. Agron. Colomb. 26(1), 32-39.

Osunde, Z.D. and B.A. Orhevba. 2009. Effects of storage conditions and storage period on nutritional and other qualities of stored yam (*Dioscorea* spp.) tubers. Afr. J. Food Agric. Nutr. Dev. 9(2), 678-690. Doi: 10.4314/ajfand.v9i2.19219

Pantoja, M. 2015. Evaluación del efecto de 3 inhibidores de brotación en papa criolla (*Solanum phureja*) variedad criolla Colombia aplicados en el proceso de postcosecha. PhD thesis. Universidad Nacional de Colombia, Bogota.

Pérez, D. and R. Campo. 2016. Efecto de la densidad poblacional sobre el rendimiento de ñame espino (*Dioscorea rotundata* Poir.) tipo exportación. Rev. Colomb. Cienc. Hortic. 10(1), 89-98. Doi: 10.17584/rcch.2016v10i1.5072

Pinzón, Y., S. Bustamante, and G. Buitrago. 2013. Diagnóstico molecular diferencial *Colletotrichum gloeosporioides* y *Fusarium oxysporum* en ñame (*Dioscorea* sp.). Rev. Colomb. Biotecnol. 15(1), 52-60.

Ramos, V.A., S.L. Bustamante, J. Rincón, M.A. Rojas, L. Raz, and G. Buitrago. 2015. Identificación, establecimiento *in vitro* y análisis fitoquímico preliminar de especies silvestres de ñame (*Dioscorea* spp.) empleadas con fines medicinales. Rev. Colomb. Biotecnol. 17(1), 9-17. Doi: 10.15446/rev.colomb.biote.v17n1.50711

Rodríguez, W. 2000. Botánica, domesticación y fisiología del cultivo de ñame (*Dioscorea alata*). Agron. Mesoam. 11(2), 133-152. Doi: 10.15517/am.v11i2.17326

Rodríguez, D., L. Rodríguez, and C. Ñústez. 2006. Heredabilidad y evaluación del contenido de proteínas totales de la colección de papa criolla (*Solanum phureja* Juz et Buk) de la Universidad Nacional de Colombia. p. 71. In: Proc. XXII Congreso de la Asociación Latinoamericana de la Papa (ALAP). Toluca, México.

Salcedo, J., J. Figueroa-Flórez, and E. Hernández. 2017. Agroindustria de productos amiláceos: II. Métodos y técnicas de caracterización. Editorial Universidad de Sucre, Sincelejo, Colombia.

Salcedo, J., C. García-Mogollón, and D. Salcedo-Hernández. 2018. Propiedades funcionales de almidones de ñame (*Dioscorea alata*). Biotecnol. Sect. Agropec. Agroind. 16(2), 99-107. Doi: 10.18684/BSAA(16)99-107

Suttle, J.C. 2004. Physiological regulation of potato tuber dormancy. Am. J. Potato Res. 81(4), 253. Doi: 10.1007/BF02871767

Tanye, R. 2016. The effects of yam post-harvest losses on food security in the Kintampo municipality of the brong ahafo region of Ghana. MSc thesis. Institute for Interdisciplinary Research and Consultancy Services (IIRaCS), University for Development Studies, Tamale, Ghana.

Techeira, N. 2008. Formulación y evaluación de productos alimenticios dirigidos al adulto mayor, a base de almidones modificados y harina de ñame (*Dioscórea alata*). PhD thesis. Universidad Central de Venezuela, Caracas.

Villar, L. 2015. Indução do atraso na brotação de gemas de 'chardonnay' (*Vitis vinifera* L.) pelo manejo de reguladores de crescimento. PhD thesis. Programa de Pós-Graduação em Recursois Genéticos Vegetais, Universidade Federal de Santa Catarina. Florianopolis, Brazil.

Xu, R.Y., Y. Niimi, and D.S. Han. 2006. Changes in endogenous abscisic acid and soluble sugars levels during dormancy-release in bulbs of *Lilium rubellum*. Sci. Hortic. 111(1), 68-72. Doi: 10.1016/j.scienta.2006.08.004