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Revista Facultad Nacional de Agronomía

Postharvest characterization of seven arracacha cultivars (*Arracacia xanthorrhiza* Bancroft)

UNIVERSIDAD NACIONAL DE COLOMBIA

Caracterización poscosecha de siete cultivares de arracacha (*Arracacia xanthorrhiza* Bancroft)

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ABSTRACT

Arracacha is used by farming families as a fundamental crop for food security because of its caloric content. In Colombia, there are diverse cultivars that have been scarcely studied. The postharvest quality and starch content of seven arracacha cultivars were characterized. A completely randomized design was used with seven treatments, consisting of the cultivars 'yema de huevo', 'paliverde', 'palirrusia', 'yucatana', 'blanca de tarro', 'palinegra' and 'amarilla de tarro'. The results showed that the pH, the total soluble solids, and the maturity ratio increased for all cultivars except for 'palinegra' during the first 8 days after harvest. The total titratable acidity decreased for 'amarilla de tarro'; in the rest of cultivars, there was a slight increase over time. The respiratory rate and firmness increased in all cultivars until day 12, with higher values for 'palinegra'. Starch content, respiratory rate, and firmness decreased, while L* increased. The loss of mass had the highest values in the first 3 days of storage. The color index and the L* and b* parameters increased over time; therefore, increases in luminosity and yellow colorations were observed. 'Paliverde' showed the highest starch content, being the cultivar less suitable for industries.

Keywords:
Firmness
Respiratory rate
Starch
Storage
Tuberous roots

RESUMEN

La arracacha está considerada dentro de un esquema de agricultura familiar como un cultivo fundamental para la seguridad alimentaria por su aporte energético. En Colombia existen una gran diversidad de cultivares que han sido poco estudiados. Por lo anterior, se caracterizó la calidad poscosecha y el contenido de almidón de siete cultivares de arracacha. Se empleó un diseño completamente al azar con siete tratamientos, conformados por los cultivares 'yema de huevo', 'paliverde', 'palirrusia', 'yucatana', 'blanca de tarro', 'palinegra' y 'amarilla de tarro'. Los resultados mostraron que el pH, los sólidos solubles totales, y la relación de madurez aumentaron para todos los cultivares excepto para el cultivar 'palinegra' durante los primeros ocho días después de la cosecha. La acidez total titulable disminuyó para 'amarilla de tarro' y en los demás cultivares se presentó un ligero aumento en el tiempo. La intensidad respiratoria y la firmeza aumentaron en todos los cultivares hasta el día 12, con mayores valores para 'palinegra'. El contenido de almidón, la intensidad respiratoria y la firmeza disminuyeron, mientras L* aumentó. La pérdida de masa presentó los mayores valores en los primeros 3 días de almacenamiento. El índice de color y los parámetros L* y b* aumentaron a través del tiempo, por lo que se apreciaron incrementos en la luminosidad y en las coloraciones amarillas. 'Paliverde' mostró los mayores contenidos de almidón, por lo que sería el cultivar menos apto para las industrias.

Palabras clave:
Firmeza
Intensidad respiratoria
Almidón
Almacenamiento
Raíces tuberosas

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In Colombia, arracacha has significant socioeconomic importance (Muñoz *et al*., 2015), and its production has increased 33.5% from 2013 to 2018, with 109,986 t with a participation of 15 departments (Agronet, 2020). An 83% of arracacha production in Colombia is concentrated in the departments of Tolima, Norte de Santander, and Boyacá, with a production of 67,586, 12,179, and 11,649 t, respectively (Agronet, 2020), which generate employment and stimulate family economies in the region (Muñoz *et al*., 2015).

The tuberous root is the most important part of arracacha since it is the commercial and edible portion of the plant (Rojas and Barreto, 2016). Arracacha can be grouped into three classes according to the color of the root epidermis: white, yellow, and purple (Muñoz *et al*., 2015). Arracacha is one of the most pleasant and nutritious native foods (Jiménez, 2005) because of its easy digestion of starches and high content of calcium, phosphorous, iron, niacin, vitamin A, ascorbic acid, proteins, fiber, and carbohydrates (Pacheco *et al*., 2020). In addition to the significant source of starch, it has ideal characteristics for agribusiness such as low gelatinization temperature, gelatinization enthalpy, a tendency to retrograde, high maximum apparent viscosity, and swelling capacity at moderate temperatures (60 °C). It has a soft and elastic gel, with high paste clarity (Castanha *et al*., 2018).

Physical, chemical, rheological, and sensory properties determine the quality of the roots and are used for selecting transformation techniques for fried chips, frozen foods, snacks, and other products (Vitti *et al*., 2003). Therefore, characterizing the properties of different arracacha cultivars during the post-harvest period is necessary to facilitate the agro-industrial implementation of these species, take advantage of their genetic diversity and encourage the productive sector to plant the cultivars that have the greatest potential for commercialization, fresh consumption, and/or agro-industrial transformation.

The limited research has hampered the implementation of good management practices in the production and postharvest process, which may have contributed to the incursion of these species in the agro-industrial sector and a decrease of constant losses of fresh products, as well as the characteristics of this cultivar. The postharvest period has not yet been evaluated and characterized for this plant; therefore, this research aimed to characterize the physical-chemical properties in the postharvest period of seven arracacha cultivars in order to provide a tool for farmers to select cultivars based on market needs.

MATERIALS AND METHODS

This research was carried out at the Plant Physiology laboratory of the Universidad Pedagógica y Tecnológica de Colombia (Boyacá, Colombia)". The arracacha roots used in the research were harvested in the municipalities of Ramiriquí, Boyacá, Turmequé, and Nuevo Colón, in the department of Boyacá.

At the harvesting stage, roots with a complete peel that was perfectly adhered to the pulp, with a diameter greater than 4 cm, whose shape was elongated, conical, and without secondary or deformed roots, were selected. The roots that presented damage, mechanical and/or attack of pests and diseases, were discarded. The roots were classified by cultivar, according to the size of the strain, the number of reserving roots, the predominant color of the root, and the presence of a purple ring (Alvarado and Ochoa, 2010). After classification, the material was stored in 20×20×7 cm extruded polystyrene foam containers.

A completely randomized design was used with 7 treatments that corresponded to different arracacha cultivars: 'yema de huevo' (YH), 'paliverde' (PV), 'palirrusia' (PR), 'yucatana' (YTN), 'blanca de tarro' (BT), 'palinegra' (PN) and 'amarilla de tarro' (AT). Each treatment had 4 replications, for a total of 28 experiment units (EU); each EU had 18 roots, harvested between 10 and 12 months after planting.

The response variables were measured every three days. The mass loss (ML) was determined using an Adam® PGW2502e 0.01 g precision electronic balance (Adam Equipment Inc, Oxford). The total soluble solids (TSS) were measured by a Hanna HI 96803 refractometer with a scale from 0 to 85% (Hanna Instruments, Spain). The pH was measured in 25 mL of arracacha juice with a Metrohm 744 digital potentiometer (Metrohm AG, Switzerland). The total titratable acidity

(TTA) was quantified following the methodology used by Rozo-Romero *et al.* (2015). The maturity ratio (MR) was expressed as the TSS/TTA ratio. The color index (CI) was calculated with Equation 1 by CIELab parameters L*, a*, and b*, which were measured using a Konica Minolta CR-20 colorimeter (Konica Minolta, Japan). Two readings were taken for each root at two equidistant points.

$$CI = \frac{1000a^*}{L^*\,b^*} \qquad (1)$$

The firmness was determined by a PCE-FM 200 digital penetrometer (PCE Ibérica SL, Albacete, Spain) by averaging two measurements in the equatorial root zone with a 6 mm tip. The respiratory rate (RR) was calculated by placing the roots in sealed 2 L SEE BC-2000 chambers (Vernier Software & Technology, OR, USA) connected to a VER CO2-BTA infrared sensor (Vernier Software & Technology, OR, USA) and a Labquest2 interface (Vernier Software & Technology, OR, USA) for 5 min, expressed in mg of CO_2 kg^{-1} h^{-1}. The starch percentage was determined according to Hernández-Medina *et al.* (2008) methodology adapted for arracacha.

A cross-sectional and longitudinal analysis of variance (ANOVA) was carried out to establish the possible statistical differences between the treatments and between times. Afterward, the Shapiro-Wilk normality test and the Levene variance homogeneity test were used for the residuals. The averages were compared with the Tukey test ($P \leq 0.05$), and a multiple linear correlation was done between the response variables. SAS® v. 9.2e was used (SAS Institute Inc., Cary, NC, USA). A cluster analysis was performed by Ward's method of minimum variance to determine the level of similarity of the postharvest physical-chemical characteristics between the evaluated plant cultivars.

RESULTS AND DISCUSSION

pH

This parameter showed significant differences between treatments in each measurement, but not between times, with values ranging between 5.2 and 6.9 (Table 1). The pH tended to increase during the first 8 days after harvest (dah) and then decreased towards 12 dah. The AT cultivar had the highest values (6.8), followed by the PN, PV, and YH cultivars with values of 6.47, while the lowest values were obtained for YTN, PR, and BT with average values of 5.69 at 8 dah. The BT cultivar often showed the lowest pH values when compared to the other cultivars evaluated.

The AT cultivar had a higher pH than BT. This latter had a longer postharvest life (17 dah), similar to what was observed by Vargas *et al.* (2017) who stated that a higher pH value indicates faster maturation and shorter shelf life. On the other hand, García and Pacheco (2008) found a pH of 6.60 and 6.65 for 'yellow' and 'white' cultivars, respectively, while Carmo and Leonel (2012) obtained values of 6.57 for the 'yellow' cultivar.

Total soluble solids (TSS)

The TSS ranged from 3.25 to 13 °Brix. There were statistical differences in the TSS values between the cultivars and times (Figure 1A and B). All cultivars showed an increase in TSS up to 8 dah and a subsequent decrease until 12 dah. The AT cultivar showed the highest TSS value for all samples (11.4 °Brix), followed by the PN cultivar (9.2 °Brix). The lowest TSS value was recorded for the PR, YTN, and BT cultivars, with a value of 6.5 °Brix at 8 dah.

Arracacha roots have 11% sucrose, 3.5% fructose, and 3.7% glucose (Pacheco *et al.*, 2020), which once synthesized, are degraded to sucrose in the cytosol of the leaves and finally exported to tissues such as roots. This may explain the initial TSS content, with subsequent degradation of starch to glucose and a corresponding increase in TSS that occurs in the postharvest period (Yahia *et al.*, 2019). A subsequent decrease in TSS, before the loss of commercial quality, may be related to changes in the RR and, therefore, in the oxidative degradation of sugars (Alós *et al.*, 2019), accompanied by tissue plasmolysis (Moreno *et al.*, 2013). Furthermore, high consumption of substrates during respiration could explain a rapid decrease in TSS (Saltveit, 2019). Barrera *et al.* (2004) found the TSS ranged from 6.1 to 9.60 in arracacha, while Buso *et al.* (2014) obtained values between 5.5 and 10.8 in arracacha coated with chitosan.

Total titratable acidity (TTA)

Statistical differences were seen in the TTA for the arracacha cultivars evaluated in each measurement, except at 8 dah. The TTA was ranged from 0.07 to 0.25%. This latter was observed in the AT cultivar (Table 1), which had the highest value with an average of 0.18%, followed by the BT cultivar with 0.14%. The lowest value was registered in the PN, YH, and PV cultivars with 0.10% at 10 dah. The TTA did not present statistically significant differences between the times for the seven arracacha cultivars. Nevertheless, a slight increase was observed up to 8 and 10 dah. The AT cultivar decreased in all measurements and 56% less TTA at the end of postharvest was recorded. A decrease in TTA is mainly attributed to the use of organic acids as respiratory substrates (Vallarino and Osorio, 2019) or the conversion to sugars through gluconeogenesis (Alós *et al.*, 2019). Ruiz (2011) determined that the TTA in arracacha was 0.74%, which was higher than the highest value found in all seven arracacha cultivars in this study (0.25%).

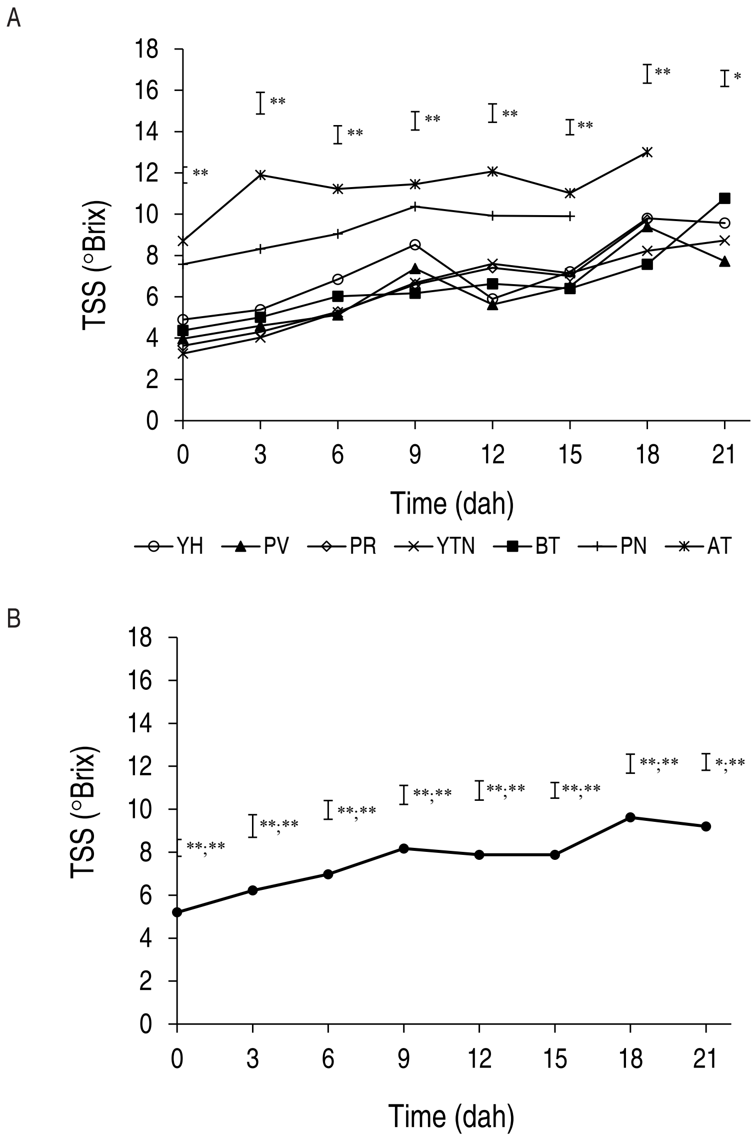

Figure 1. TSS A. in the different arracacha cultivars. B. average. YH: yema de huevo. PR: palirrusia. BT: blanca de tarro. AT: amarilla de tarro. PV: paliverde. YTN: yucatana. Vertical bars indicate the standard error (n=28). * and ** indicate significant effect according to the Tukey test for $P \leq 0.05$ and $P \leq 0.01$, respectively, between treatments before the semicolon and between times after the semicolon.

Table 1. pH, TTA, and MR parameters evaluated on roots of different arracacha cultivars during the postharvest period.

Parameter	dah	Treatments						
		YH	PV	PR	YTN	BT	PN	AT
pH	0	5.5±0.16^{B,d}	6.19±0.11^{B,b}	5.38±0.07^{B,c}	5.39±0.14^{B,a}	5.33±0.05^{B,c}	6.45±0.26^{AB,a}	6.65±0.1^{A,a}
	3	5.74±0.2^{B,d}	6.41±0.08^{B,b}	5.57±0.04^{B,bc}	5.59±0.14^{B,a}	5.54±0.05^{B,c}	6.26±0.21^{B,a}	6.85±0.06^{A,a}
	6	6.41±0.08^{B,abc}	6.18±0.06^{B,b}	5.58±0.07^{B,bc}	5.86±0.06^{B,a}	5.62±0.004^{B,c}	6.14±0.21^{B,a}	6.92±0.07^{A,a}
	9	6.54±0.06^{B,abc}	6.47±0.02^{B,b}	5.66±0.09^{C,bc}	5.89±0.05^{C,a}	5.52±0.05^{C,c}	6.4±0.15^{B,a}	6.94±0.02^{A,a}
	12	6.11±0.08^{BCD,cd}	6.4±0.07^{B,b}	5.86±0.15^{CD,ab}	5.62±0.08^{D,a}	5.63±0.1^{D,c}	6.35±0.19^{BC,a}	6.79±0.02^{A,a}
	15	6.11±0.11^{BC,bcd}	5.99±0.07^{BC,b}	5.59±0.18^{C,bc}	5.53±0.06^{C,a}	5.22±0.11^{C,c}	6.34±0.25^{D,a}	6.8±0.02^{A,a}
	18	6.23±0.12^{B,bcd}	6.39±0.06^{AB,b}	6.07±0.03^{B,a}	6.28±0.2^{B,a}	5.89±0.05^{B,b}	---	6.72±0.1^{A,a}
	21	6.48±0.1^{B,ab}	6.93±0.04^{A,a}	---	5.87±0.11^{C,a}	6.09±0.02^{BC,a}	---	---
TTA (%)	0	0.07±0.004^{B,a}	0.08±0.007^{B,a}	0.11±0.017^{B,a}	0.08±0.008^{B,c}	0.11±0.009^{B,d}	0.11±0.011^{B,a}	0.23±0.011^{A,ab}
	3	0.09±0.017^{B,a}	0.08±0.001^{B,a}	0.12±0.017^{B,a}	0.1±0.005^{B,bc}	0.12±0.009^{B,cd}	0.12±0.012^{B,a}	0.25±0.019^{A,a}
	6	0.07±0.018^{B,a}	0.08±0.005^{B,a}	0.13±0.02^{AB,a}	0.12±0.007^{AB,abc}	0.14±0.014^{AB,bcd}	0.14±0.027^{AB,a}	0.21±0.04^{A,abc}
	9	0.14±0.008^{A,a}	0.11±0.011^{A,a}	0.16±0.04^{A,a}	0.12±0.021^{A,abc}	0.14±0.007^{A,bcd}	0.09±0.007^{A,a}	0.14±0.016^{A,bc}
	12	0.1±0.012^{A,a}	0.1±0.027^{A,a}	0.1±0.015^{A,a}	0.2±0.048^{A,a}	0.14±0.016^{A,bcd}	0.11±0.008^{A,a}	0.16±0.013^{A,abc}
	15	0.1±0.015^{B,a}	0.12±0.014^{AB,a}	0.16±0.027^{AB,a}	0.15±0.007^{AB,abc}	0.17±0.009^{A,ab}	0.12±0.018^{AB,a}	0.14±0.011^{AB,c}
	18	0.13±0.026^{AB,a}	0.12±0.009^{AB,a}	0.09±0.009^{B,a}	0.15±0.009^{AB,abc}	0.16±0.008^{A,bc}	---	0.14±0.009^{AB,bc}
	21	0.1±0.017^{B,a}	0.07±0.008^{B,a}	---	0.18±0.019^{A,ab}	0.21±0.003^{A,a}	---	---
MR	0	67.1±3.78^{AB,a}	49.38±4.69A^{BC,b}	33.84±5.86^{C,b}	41.71±6.27^{BC,a}	41.15±4.47^{BC,a}	70.57±10.1^{A,a}	37.68±3^{C,b}
	3	57.1±9.13^{AB,a}	54.41±3.41^{AB,b}	35.45±6.86^{B,b}	39.46±2.99^{B,a}	40.15±1.48^{B,a}	66.85±7.75^{A,a}	47.98±6.02^{AB,ab}
	6	93.81±25.74^{A,a}	60.9±3.45^{AB,b}	40.86±12.15A^{B,b}	43.86±4.5A^{B,a}	42.32±3.55^{B,a}	64.54±18.81^{AB,a}	52.63±18.37^{AB,ab}
	9	61.99±7.43^{B,a}	66.9±8.88^{B,ab}	40.39±6.04^{B,b}	57.04±21.91^{B,a}	44.63±1.94^{B,a}	120.34±8.01^{A,a}	81.59±6.83^{AB,a}
	12	58.48±9.25A^{B,a}	53.86±20.15^{AB,b}	71.76±14.54^{AB,ab}	37.29±6.78^{B,a}	48.32±5.22^{AB,a}	92.71±8.12^{A,a}	75.2±5.45^{AB,ab}
	15	74.15±12.91A^{B,a}	55.88±8.21^{AB,b}	42.66±11.82^{AB,b}	46.22±3.33^{AB,a}	37.18±2.85^{B,a}	81.89±13.33^{A,a}	80.88±11.46^{AB,a}
	18	76±11.64^{ABC,a}	79.88±8.67A^{BC,ab}	105.86±13.03^{A,a}	56.64±4.3^{BC,a}	48.23±4.12^{C,a}	---	91.86±8.17^{AB,a}
	21	91.74±8.04^{A,a}	112.82±11.94^{A,a}	---	48.64±7.99^{B,a}	52.21±1.54^{B,a}	---	---

Means of 4 replicates ± standard error. YH: yema de huevo, PV: paliverde, PR: palirrusia, YTN: yucatana, BT: blanca de tarro, PN: palinegra and AT: amarilla de tarro. TTA: total titratable acidity, MR: maturity ratio. Mean values in the rows with different uppercase letters have statistically significant differences ($P \leq 0.05$) between treatments. Mean values in the columns with different lowercase letters have statistically significant differences ($P \leq 0.05$) between times. ---: loss of consumer quality.

Maturity ratio (MR)

The MR increased in the final measurements in all arracacha cultivars. Statistical differences between cultivars were observed for all measurements, except at 10 dah (Table 1). At 10 and 12 dah, there was a decrease in the MR. Moreover, there were statistical differences for the MR over time. The PN and AT cultivars showed higher MR values (86.5 and 76.8, respectively). The YTN and BT cultivars had lower MR values with averages of 45.2 and 43.3, respectively.

In tuberous roots, an increase in the MR means a better flavor because of an increase in TSS (R^2=0.4857), which indicates better organoleptic characteristics (Figueiredo *et al.*, 2011). Once tuberous roots are harvested, the formation of α-amylase enzymes begins, which together with β-amylases degrade starch, generating sweet flavors in the cultivars (Alós *et al.*, 2019). García and Pacheco (2008), based on a quantification of TSS and TTA in arracacha, found average values of MR for white and yellow morphotypes of 84.78 and 83.72, respectively, like those found for PN and YH.

Firmness

The firmness showed significant statistical differences between cultivars and times, except at 10 dah. The initial values ranged from 9.1 to 16.7 N and subsequently, they increased (Table 2). The firmness decreased in the arracacha cultivars at 8, 10, and 12 dah. The PR cultivar displayed increased firmness over time from 12.4 to 44.9 N, which was the highest one, followed by the PV and YTN cultivars, with an increase from 10.1 to 35.3 N and 11.1 to 33.98 N, respectively.

Table 2. Firmness and respiratory rate of different arracacha cultivars during the postharvest period.

Parameter	dah	Treatments						
		YH	PV	PR	YTN	BT	PN	AT
Firmness (N)	0	$9.12\pm0.21^{C,c}$	$10.11\pm0.27^{C,e}$	$12.46\pm0.37^{BC,e}$	$11.18\pm0.12^{C,e}$	$11.13\pm0.34^{C,f}$	$16.71\pm0.66^{A,c}$	$15.73\pm1.71^{AB,a}$
	3	$10.78\pm0.67^{C,c}$	$14.15\pm1.12^{BC,de}$	$15.73\pm1.34^{BC,de}$	$16.53\pm1.17^{BC,de}$	$16.58\pm0.61^{BC,e}$	$23.53\pm1.17^{AB,b}$	$17.3\pm2.61^{A,a}$
	6	$12.43\pm1.33^{B,c}$	$18.58\pm2.27^{AB,cde}$	$19.06\pm2.21^{AB,cde}$	$22.58\pm2.05^{A,cde}$	$22.08\pm1.1^{A,d}$	$25.32\pm1.23^{A,ab}$	$19.65\pm2.84^{AB,a}$
	9	$24.73\pm3.57^{AB,ab}$	$29.08\pm1.59^{A,ab}$	$31.28\pm1.39^{A,d}$	$27.68\pm2.52^{AB,bc}$	$22.55\pm0.78^{AB,cd}$	$29.2\pm1.26^{A,a}$	$18.38\pm1.88^{B,a}$
	12	$23.8\pm2.34^{A,ab}$	$24.53\pm1.08^{A,bc}$	$27.18\pm1.93^{A,bc}$	$29.7\pm1.11^{A,bc}$	$26.46\pm1.46^{A,dc}$	$25.2\pm1.01^{A,ab}$	$24.7\pm1.36^{A,a}$
	15	$30.25\pm2.5^{BC,ab}$	$35.33\pm2.39^{AB,a}$	$44.95\pm3.4^{A,a}$	$33.98\pm1.44^{B,ab}$	$30.33\pm0.88^{BC,ab}$	$21.3\pm1.83^{C,bc}$	$20.87\pm3.04^{C,a}$
	18	$23.75\pm0.74^{A,ab}$	$26.73\pm1.81^{A,abc}$	$24.28\pm1.51^{A,bcd}$	$24.9\pm1.5^{A,c}$	$23.38\pm0.41^{A,cd}$	---	$22.03\pm1.72^{A,a}$
	21	$18.35\pm1.99^{B,bc}$	$22.55\pm3.36^{B,bcd}$	---	$38\pm1.78^{A,a}$	$33.25\pm1.03^{A,a}$	---	---
RR ($mg.CO_2.kg^{-1}.h^{-1}$)	0	$16.85\pm2.3^{A,ab}$	$17.44\pm1.21^{A,a}$	$18.83\pm1.14^{A,ab}$	$17.52\pm3.28^{A,abc}$	$18.75\pm1.63^{A,a}$	$19.09\pm3.32^{A,a}$	$15.22\pm3.81^{A,b}$
	3	$17.42\pm0.47^{BC,ab}$	$16.56\pm1.36^{C,a}$	$19.31\pm1.77^{BC,ab}$	$14.16\pm2.12^{C,abc}$	$18.35\pm0.51^{BC,a}$	$25.4\pm3.71^{B,a}$	$34.49\pm0.72^{A,a}$
	6	$18.12\pm2.23^{AB,ab}$	$15.75\pm3.5^{AB,a}$	$20.73\pm3.6^{AB,ab}$	$10.16\pm1.4^{B,c}$	$17.41\pm1.42^{AB,a}$	$26.58\pm2.74^{A,a}$	$25.05\pm3.67^{A,ab}$
	9	$26.83\pm3.34^{A,a}$	$26.78\pm5.52^{A,a}$	$25.45\pm3.06^{A,ab}$	$15.71\pm2.38^{A,abc}$	$17.22\pm0.84^{A,a}$	$27.06\pm4.85^{A,a}$	$28.96\pm4.58^{A,ab}$
	12	$16.64\pm1.44^{B,b}$	$15.29\pm2.04^{B,a}$	$31.44\pm4.51^{AB,a}$	$20.55\pm0.63^{AB,ab}$	$19.09\pm1.15^{AB,a}$	$36.13\pm7.34^{A,a}$	$26.25\pm4.92^{AB,ab}$
	15	$16.32\pm1.82^{B,b}$	$15.83\pm0.48^{B,a}$	$30.66\pm2.46^{A,ab}$	$17.72\pm2.22^{B,abc}$	$15.34\pm3.46^{B,a}$	$21.58\pm3.92^{AB,a}$	$22.95\pm1.99^{AB,ab}$
	18	$19.95\pm2.34^{ABC,ab}$	$16.16\pm1.63^{BC,a}$	$18.14\pm1.34^{ABC,b}$	$23.1\pm1.93^{AB,a}$	$14.62\pm0.15^{C,a}$	---	$23.6\pm1.25^{A,ab}$
	21	$15.75\pm2.14^{A,b}$	$16.77\pm2.83^{A,a}$	---	$13.62\pm0.73^{A,bc}$	$20.81\pm1.58^{A,a}$	---	---

Means of 4 replicates ± standard error. YH: yema de huevo, PV: paliverde, PR: palirrusia, YTN: yucatana, BT: blanca de tarro, PN: palinegra and AT: amarilla de tarro. RR: respiratory rate. Mean values in the rows with different uppercase letters are significantly different ($P\leq0.05$) between treatments. Mean values in the columns with different lowercase letters are significantly different ($P\leq0.05$) between times. ---: loss of consumer quality.

An increase in firmness occurs because of the formation of hard consistencies related to the synthesis of lignin from soluble carbohydrates (Yahia *et al.*, 2019), similar results were reported by Rainoso (2010) who found that lignin increased from 1.54 to 2.38% in the first 9 days postharvest in arracacha, while a decrease in firmness is probably due to the degradation of pectins as a result of the increased activity of polygalacturonase, generating softness in plant material (Nunes, 2010), comparable with the results obtained for the AT and PN cultivars at 8 dah and the other cultivars at 10 and 12 dah. Ruiz (2011) found that the firmness of arracacha was 37.16 N, like PR, PV, and YTN.

Starch

The starch content presented statistical differences between cultivars and times from the first day of storage and up to 15 dah. The initial starch values ranged from 12.5 to 23.8% (Figure 2). The starch content tended to decrease until 10 and 12 dah, after that there was a slight increase in some evaluated cultivars. PV cultivar had the highest starch content (16.7%), followed by PR and YTN cultivars (13.5%) at 10 dah, while the lowest values were obtained for PN and AT with 11.2%. Starch contents of 19.53 and 11.1% have been found in arracacha by Souza (2013) and Alayo (2015), respectively, similar to those seen for AT.

The increase in starch contents at 10 dah can be attributed to the fact that, at the last postharvest stage, the loss of water from the cultivar is high and the concentration of starch rises despite the amount is lower than at the beginning of the postharvest stage, known as the dilution effect; another less probable theory for the increase in starch in the postharvest stage involves the reconversion of sugars into starch, promoted by the enzyme starch synthase (Yahia *et al.*, 2019).

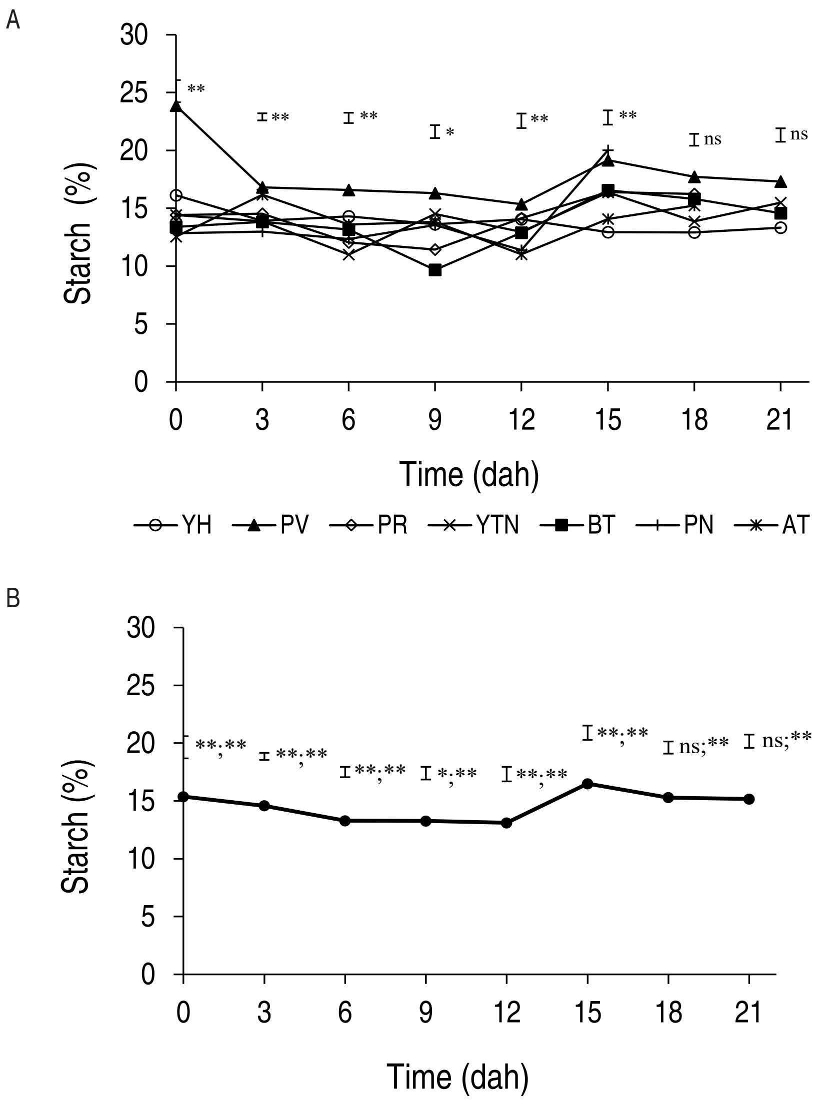

Figure 2. Starch A. in the different arracacha cultivars. B. average. YH: yema de huevo. PR: palirrusia. BT: blanca de tarro. AT: amarilla de tarro. PV: paliverde. YTN: yucatana. Vertical bars indicate the standard error (n=28). * and ** indicates significant effect according to the Tukey test for $P\leq 0.05$ and $P\leq 0.01$, respectively, between treatments before the semicolon and between times after the semicolon.

Respiratory rate (RR)

Statistical differences between the cultivars and times were observed (3, 5, 10, 12, and 15 dah). Initially, the RR ranged between 15.2 and 19.09 mg of CO_2 kg^{-1} h^{-1}, then had a peak at 8 and 10 dah, and subsequently decreased (Table 2). The highest RR was observed for PN at 10 dah (36.13 mg of CO_2 kg^{-1} h^{-1}), followed by AT and PR cultivars (25.87 and 24.98 mg of CO_2 kg^{-1} h^{-1}, respectively).

An increase in RR is correlated with an increase in the activity of ethylene (Iqbal *et al.*, 2017), caused by the stress suffered by roots when are extracted from the plant at the harvest stage since this increases energy demand (Munné-Bosch *et al.,* 2018) and the starch and sugar reserves are used in metabolic processes such as tissue softening, pigmentation and volatile synthesis (Saltveit, 2019), which explains the dynamics of the PN, AT and PR cultivars with a higher RR and shorter postharvest life. Henz *et al.* (2005) found that, in undamaged arracacha roots, the RR was 15.3 and 3.8 mg of CO_2 kg^{-1} h^{-1} at room temperature and refrigeration, respectively. Similarly, Rainoso (2010) stated that the RR of arracacha roots increases until the fifth and seventh day and subsequently stabilizes and/or begins to decrease. Nunes *et al.* (2010) found that RR in arracacha ranged from 8.48 to 44.25 mg of CO_2 kg^{-1} h^{-1}, similar to the values for PN and AT of this study.

Mass loss (ML)

Statistically significant differences between times and treatments were observed for all measurements. ML increased significantly up to 3 dah in the BT, PR, and YTN cultivars (Figure 3A and B), similar to that was observed in *Daucus carota* (Araujo *et al.*, 2004). ML in all seven cultivars for the measurements at 15 and 17 dah was about 66%. Cultivars with higher ML values were BT (81.7%) and PR (75.7%), followed by PV and YTN cultivars with 66.1%. Lower ML values were for AT and PN with 41.6 and 46.3%, respectively.

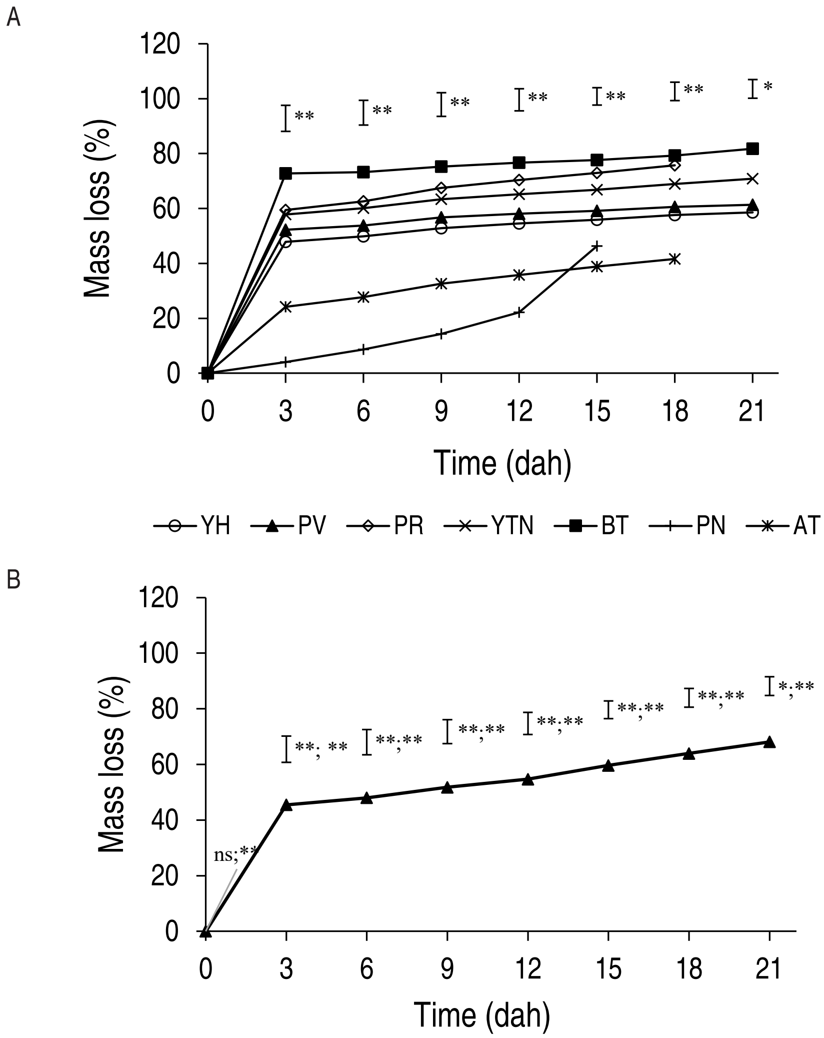

Figure 3. Mass loss A. in the different arracacha cultivars, B. average. YH: yema de huevo. PR: palirrusia. BT: blanca de tarro. AT: amarilla de tarro. PV: paliverde. YTN: yucatana. Vertical bars indicate the standard error (n=28). * and ** indicates significant effect according to the Tukey test for $P \leq 0.05$ and $P \leq 0.01$, respectively, between treatments before the semicolon and between times after the semicolon.

The highest firmness values and the lowest the ML are in arracacha (R^2=0.5018 from correlation analysis), possibly because these roots have more efficient structures that prevent dehydration. According to Link *et al.* (2004), weak cell walls and membranes allow water to escape through respiration at a higher speed, which depends on the pressure of the water vapor, the evaporation surface, and the resistance to the diffusivity of the product to the environment. A water loss of 7% is the maximum commercially allowed for roots (Díaz-Pérez, 2019).

CIEL*a*b* space

Parameter L*, statistical differences between cultivars and times were observed (except at 18 and 21 dah). It was observed that L* tended to increase in all cultivars up to 15 dah and then decreased, except in AT, which presented a decrease of 21.5% (Table 3). L* increased for PV and YTN cultivars by 14 and 12%, respectively, followed by BT (9.7%), YH (9.3%), PN (5.10%), and PR (4.99%).

The cultivars presented lighter colorations over time, except for AT cultivar, in which the coloration darkened during storage. An increase in luminosity is due to the loss of water (Vitti *et al.*, 2003) and also the increase in yellow shades (Jha *et al.*, 2006), which is correlated with the increase of b* in arracacha roots (R^2=0.6196). Carmo and Leonel (2012) found that in 'yellow' cultivar, L* ranged from 70.6 to 76.5, while García and Pacheco (2008) found values of 73.14 and 77.89 for 'white' and 'yellow' cultivars, similar to what was observed in BT, YTN, and PR.

Parameter a*, statistically significant differences were observed between the cultivars for a* value, except at 12 and 15 dah. The initial values ranged between 5.9 and 10.03, and at the end of the period were between 8.15 and 10.5 (Table 3). There were significant differences over time, the a* values had a slightly increasing trend after 8 dah. Besides, this parameter presented positive values, which indicated the absence of green colorations. Salas (2018) stated that β-carotene is the predominant pigment in arracacha and that, at the postharvest stage, it can increase its concentration as a result of the dilution effect that is generated by the loss of water from the material. On the other hand, Carmo and Leonel (2012) found a* values that ranged from 0.27 to 3.71 for "yellow" arracachas, lower values than those found in this research.

Parameter b*, statistically significant differences between the cultivars and times were observed for all measurements, except at 18 dah. The initial and final b* values ranged from 11.43 to 26.03 and from 18.95 to 26.8, respectively (Table 3). b* value decreased until 5 and 8 dah and then increased, except for AT and PN cultivars, which decreased constantly. At the postharvest, PV and BT presented increases of 39.7% and 28.9%, respectively, followed by the YTN cultivar (21.7%), YH (19%), and PR (7.9%). b* had positive values in all cultivars, indicating the absence of blue tones and a predominance of yellow ones; the latter is associated with the synthesis of carotenoids that increase during the first 15 dah. b* values have been found to range from 34.3 to 42.6 (Carmo and Leonel, 2012), higher values than the 'white' materials (21.91) evaluated by García and Pacheco (2008).

Color index (CI)

The CI had statistically significant differences between the cultivars, but not between times. The initial values ranged between 3.73 and 15.34, and the final values were between 5.18 and 9.22 (Table 3). After 8 dah, the CI remained constant. The YH and PV cultivars presented the highest CI with 15.46 and 21.31, respectively, while BT showed the lowest CI with 3.13. Differences in the CI can be attributed to different levels of carotenoids, phenolic compounds, and enzymatic activity of polyphenol oxidase in each cultivar (Enríquez *et al.*, 2020), while a decrease in CI probably occurs as a result of the instability of the carotenoids, as they are easily degraded thanks to the oxidative processes, light, and pH (Meléndez *et al.*, 2004).

Cluster analysis

According to the cluster analysis, the cultivars were classified into two large groups (Figure 4). The first group includes the PN and AT cultivars, which had similar characteristics, pH and TSS values were higher than those of the second group, which is formed by the YH, PV, PR, YTN, and BT cultivars. A subgroup was created for the YTN and BT cultivars, which had similar firmness values (11.17 and 11.12 N, respectively), and showed a difference with the rest of the cultivars. Within the second group, the YH cultivar had the highest RR.

Table 3. Color parameters evaluated on roots of different arracacha cultivars during the postharvest period.

Parameter	dah	Treatments						
		YH	PV	PR	YTN	BT	PN	AT
L*	0	65.58±1.07^{A,a}	51.63±3.31^{BC,ab}	49.63±3.38^{BC,a}	57.08±1.75^{ABC,ab}	60.3±1.61^{AB,ab}	49.05±2.86^{C,a}	58.18±1.54^{ABC,a}
	3	67.68±1.28^{A,a}	56.28±5.64^{ABC,ab}	50.73±2.48^{BC,a}	58±1.68^{ABC,ab}	59.89±1.2^{AB,abc}	47.3±2.09^{C,a}	55.8±1.35^{ABC,ab}
	6	53.65±1.59^{A,b}	47.63±2.15^{AB,b}	43.15±2.19^{B,a}	49.93±2.51^{AB,b}	53.1±0.87^{A,bc}	53.35±0.54^{A,a}	55.45±2.28^{A,ab}
	9	68.63±1.33^{A,a}	57.9±5.19^{AB,ab}	51.3±1.97^{B,a}	59.43±2.01^{AB,ab}	59.75±1.39^{AB,abc}	51.45±1.2^{B,a}	51.73±0.73^{B,abc}
	12	69.93±2.36^{A,a}	58.9±3.03^{B,a}	47.45±3.33^{C,a}	55.78±2.67^{BC,ab}	52.73±1.06^{BC,c}	52.25±1.76^{BC,a}	52.18±1.67^{BC,ab}
	15	71.25±0.6^{A,a}	65.35±0.83^{AB,ab}	54.33±1.7^{C,a}	62.98±2.74^{B,a}	65.5±1.14^{AB,a}	51.55±0.9^{C,a}	51.53±0.99^{C,bc}
	18	72.45±2.48^{A,a}	61.65±2.31^{BC,ab}	52.1±3.42^{CD,a}	61.7±2.56B^{C,a}	64.23±1.97^{AB,a}	---	45.63±0.6^{D,c}
	21	71.65±1.7^{A,a}	59.2±2.26^{B,ab}	---	64.25±1.98^{AB,a}	66.15±2.66^{AB,a}	---	---
a*	0	5.9±0.55^{B,c}	9.05±0.85^{AB,b}	10.03±0.45^{A,ab}	7.63±0.88^{AB,a}	6.63±0.49^{AB,c}	9.35±1.26^{AB,a}	9.25±0.71^{AB,a}
	3	6.03±0.56^{B,c}	8.28±0.88^{AB,b}	9.68±0.4^{A,ab}	7.5±0.76^{AB,a}	7.15±0.36^{AB,c}	9.7±0.47^{A,a}	7.35±0.3^{AB,a}
	6	17.13±1.41^{A,a}	13.58±1.29^{AB,a}	5.43±0.7^{CD,c}	3.28±1.88^{D,b}	2.95±1.02^{D,d}	9±0.56B^{C,a}	8.6±0.33^{BC,a}
	9	6.63±0.61^{B,bc}	7.55±0.8^{AB,b}	8.08±0.51^{AB,b}	7.1±0.5^{AB,ab}	6.9±0.3^{B,c}	9.48±0.35^{A,a}	8.35±0.57^{AB,a}
	12	8.73±0.72^{A,bc}	10.53±0.87^{A,ab}	10.23±0.52^{A,ab}	8.83±0.47^{A,a}	8.53±0.37^{A,bc}	9.68±0.46^{A,a}	8.4±0.78^{A,a}
	15	8.78±0.79^{A,bc}	10.73±0.8^{A,ab}	10.83±0.23^{A,a}	9.55±0.8^{A,a}	11.01±0.3^{A,a}	8.88±0.26^{A,a}	8.63±0.7^{A,a}
	18	8.93±0.45^{AB,bc}	10.83±0.55^{A,ab}	10.5±0.37^{A,a}	9.53±0.59^{AB,a}	10.48±0.63^{A,ab}	---	8.15±0.21^{B,a}
	21	9.83±0.41^{A,b}	9.4±0.51^{A,b}	---	9.95±0.33^{A,a}	10.05±0.32^{A,ab}	---	---
b*	0	24.15±0.76^{A,cd}	11.43±1.56^{B,c}	18.85±1.55^{AB,ab}	19.85±0.27^{A,bc}	19.08±0.28^{AB,bc}	25.95±3.71^{A,a}	26.03±1.95^{A,a}
	3	24.78±0.35^{A,bcd}	24.73±1.23^{A,a}	18.55±1.2^{B,ab}	19.88±0.27^{AB,bc}	20.29±0.26^{AB,bc}	24.31±2.12^{A,a}	21.65±0.58^{AB,ab}
	6	20.65±0.69^{AB,d}	13.38±1.53^{C,bc}	14.3±1.4^{C,b}	16.55±0.53^{BC,c}	17.73±0.33^{ABC,c}	22.7±1.07^{A,a}	21.5±1.83^{AB,ab}
	9	23.78±0.55^{A,cd}	17.43±3.25^{BC,abc}	15.2±0.89^{C,b}	17.85±0.39^{ABC,c}	17.95±0.37^{ABC,c}	21.88±1.1^{AB,a}	22.37±0.3^{AB,ab}
	12	30.75±0.98^{A,a}	18.98±0.38^{C,abc}	20.6±0.73B^{C,a}	22.83±0.63^{B,ab}	21.85±0.17^{BC,b}	22.55±0.76^{BC,a}	20.2±1.34^{BC,ab}
	15	28.98±0.67^{A,abc}	21.2±0.36^{C,ab}	21.38±0.65^{C,a}	24.55±1.76^{DC,a}	26.93±0.14^{AB,a}	20.33±0.86^{C,a}	20.8±1.17^{C,ab}
	18	29.8±1.29^{A,ab}	18.18±1.83^{D,abc}	20.48±0.82^{BCD,a}	25.2±1.57^{ABC,a}	26.38±0.12^{AB,a}	---	19.38±1.9^{CD,b}
	21	26.48±2.42A,^{abc}	18.95±2.56^{A,abc}	---	25.35±0.68^{A,a}	26.83±1.71^{A,a}	---	---
CI	0	3.73±0.39^{B,b}	15.34±3.75^{A,ab}	10.72±0.96^{AB,a}	6.73±0.94^{B,a}	5.76±0.62^{B,ab}	7.35±1.77^{B,a}	6.11±0.2^{B,b}
	3	3.59±0.35^{C,b}	5.95±1.01^{BC,b}	10.28±0.76^{A,a}	6.51±0.74^{BC,a}	5.88±0.37^{BC,ab}	8.44±1.5^{AB,a}	6.08±0.31^{BC,b}
	6	15.46±1.73^{AB,a}	21.31±5.3^{A,a}	8.79±0.33^{BC,a}	3.96±2.5^{C,a}	3.13±1.15^{C,b}	7.43±0.28^{BC,a}	7.21±0.9^{BC,ab}
	9	4.06±0.37^{C,b}	7.48±1.72^{AB,b}	10.36±0.84^{A,a}	6.69±0.74^{ABC,a}	6.43±0.46^{BC,a}	8.42±0.18^{AB,a}	7.22±0.46^{ABC,ab}
	12	4.06±0.3^{C,b}	9.42±0.45^{AB,b}	10.46±0.95^{A,a}	6.93±0.27^{B,a}	7.4±0.42^{B,a}	8.21±0.53^{AB,a}	7.97±0.69^{D,ab}
	15	4.25±0.32^{C,b}	7.74±0.76^{AB,b}	9.32±0.37^{A,a}	6.18±0.4^{B,a}	6.24±0.3^{B,a}	8.47±0.29^{A,a}	8.05±0.2^{AB,ab}
	18	4.13±0.47^{B,b}	9.66±0.95^{A,b}	9.84±0.74^{A,a}	6.13±0.29^{B,a}	6.18±0.49^{B,a}	---	9.22±1.07^{A,a}
	21	5.18±0.91^{A,b}	8.38±1.93^{A,b}	---	6.11±0.48^{A,a}	5.66±0.74A,^{ab}	---	---

Means of 4 replicates ± standard error. YH: yema de huevo, PV: paliverde, PR: palirrusia, YTN: yucatana, BT: blanca de tarro, PN: palinegra and AT: amarilla de tarro. CI: color index. Mean values in the rows with different uppercase letters are significantly different ($P\leq0.05$) between treatments. Mean values in the columns with different lowercase letters are significantly different ($P\leq0.05$) between times. ---: loss of consumer quality.

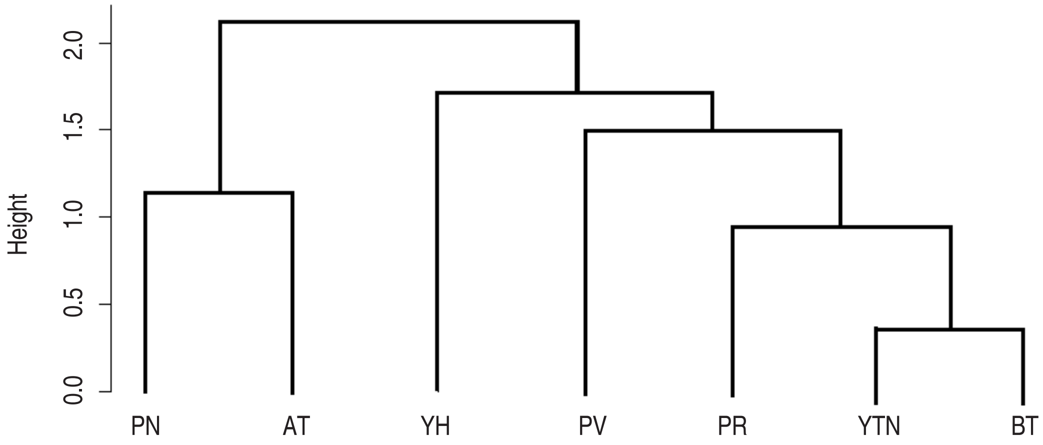

Figure 4. Dendrogram of arracacha cultivars. YH: yema de huevo, PV: paliverde, PR: palirrusia, YTN: yucatana, PN: palinegra and AT: amarilla de tarro.

CONCLUSION

The pH and TSS tended to increase in all cultivars, except for PN. The highest pH and TSS values were recorded in the AT, PN, and PV cultivars. The firmness of the arracacha roots increased at the postharvest stage up to 10 dah and the PN, AT and PR cultivars presented the highest value. The highest ML in the arracacha roots occurred at the first 3 dah. PV showed the highest starch content. After the postharvest stage, arracacha increases yellow tones and luminosity; the latter is inversely proportional to the starch content. In future studies, the application of maturity retardants is recommended in order to prolong the storage life.

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