Physical and chemical characterization of yacon (*Smallanthus sonchifolius*) roots cultivated with different doses of potassium fertilization

Caracterización física y química de raíces de yacón (*Smallanthus sonchifolius*) cultivadas con diferentes dosis de fertilización potásica

Amanda Dutra de Vargas [1*], Fábio Luiz de Oliveira [1], Luciano José Quintão Teixeira [2], Mateus Oliveira Cabral [1], Lidiane dos Santos Gomes Oliveira [1], Joab Luhan Ferreira Pedrosa [1]

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Abstract

The already marked tendency for functional food consumption, low in calories, and with biologically active properties, has been increasing. In this scenario, yacon tuberous roots, with high levels of nutraceutical fructooligosaccharides, gain importance. However, these nutraceutical properties depend on fertilization management. Thus, our study aims to evaluate different doses of potassium fertilization on the physicochemical characteristics of yacon roots. The experimental design consisted of randomized blocks, with 4 replications and 5 treatments: four doses of potassium fertilization (50%; 100%; 150%; 200%) of the reference value, corresponding to 178.7 $kg.ha^{-1}$; 357.4 $kg.ha^{-1}$; 536.1 $kg.ha^{-1}$; 714.8 $kg.ha^{-1}$ of potassium chloride – (KCl), and a control (soil without fertilization). The chemical features evaluated were pH, total titratable acidity, soluble solids, conductivity, turbidity, moisture and ashes. The texture profile was analyzed through toughness, adhesiveness, cohesiveness, chewability index, elasticity, and gooeyness. Most of the variables were influenced by potassium soil fertilization. Only turbidity, conductivity and gumminess showed no response to the applied doses, not fitting the tested models. Potassium fertilization improved both chemical (higher levels of soluble solids and less acidity) and physical characteristics (less hardness, chewability, cohesiveness, and adhesion) of yacon tuberous roots, bringing greater quality to the final product.

Keywords

Smallanthus sonchifolius • fructooligosaccharides • functional food • tuberous roots

1 Universidade Federal do Espírito Santo. Departamento de Agronomia. Centro de Ciências Agrárias e Engenharias. Alegre. Espírito Santo. Brasil.
* amandadvargas@hotmail.com

2 Universidade Federal do Espírito Santo. Departamento de Engenharia de Alimentos. Centro de Ciências Agrárias e Engenharias. Alegre. Espírito Santo. Brasil.

Resumen

La tendencia en el consumo de alimentos funcionales, con pocas calorías y con propiedades biológicamente activas, ha ido en aumento. El consumo de raíces tuberosas de yacón se adapta a este concepto por los altos niveles de fructooligosacáridos, lo que le confiere propiedades nutracéuticas. Sin embargo, estas propiedades pueden modularse mediante el manejo de la fertilización en el cultivo de esta planta. Así, nuestro estudio tiene como objetivo evaluar diferentes dosis de fertilización potásica en las características fisicoquímicas de las raíces de yacón. El diseño experimental utilizado fue de bloques al azar, con 4 repeticiones y 5 tratamientos: cuatro dosis de fertilización potásica (50%; 100%; 150%; 200%) del valor de referencia, correspondiente a 178,7 $kg.ha^{-1}$; 357,4 $kg.ha^{-1}$; 536,1 $kg.ha^{-1}$; 714,8 $kg.ha^{-1}$ de cloruro de potasio - (KCl), y un testigo (suelo sin fertilizar). Las características químicas evaluadas fueron pH, acidez total titulable, sólidos solubles, conductividad, turbidez, porcentaje de humedad y cenizas. El perfil de textura se elaboró analizando la tenacidad, la adhesividad, la cohesión, el índice de masticabilidad, la elasticidad y la pegajosidad. La fertilización con potasio mejoró las características químicas (mayores niveles de sólidos solubles y menor acidez) y las características físicas (menor dureza, masticabilidad, cohesión y adherencia) de las raíces tuberosas de yacón, aportando mayor calidad al producto final.

Palabras clave

Smallanthus sonchifolius • fructooligosacáridos • comida functional • raíces tuberosas

Introduction

The search for foods with low carbohydrates and greater amounts of antioxidants and vitamins, *i.e.* with biologically active value, has increased (11). In this context, yacon (*Smallanthus sonchifolius*) an Asteraceae of Andean origin, gains importance for its tuberous roots with high concentrations of inulin and fructooligosaccharides (FOS) (4).

Yacon is considered a prebiotic food. Several immunostimulatory characteristics promote antimicrobial, anti-inflammatory, and antioxidant activity (51). It also acts in the regulation of appetite (45), increasing mineral availability (23), positively modulating the immune system (52), in the hypolipidemic effect (33) and preventing diseases such as diabetes and cancer (40).

The tuberous roots of yacon are sweet and slightly crunchy, resembling fruits such as apple, pear, watermelon, and melon, mostly consumed in fresh. However, other forms of consumption have also been studied (24).

Chemical characteristics, such as pH, soluble solids, and total titratable acidity, together with texture, flavor, and appearance constitute some of the quality attributes leading consumers to accept or reject a given food (28). Variations in the physical and chemical characteristics of yacon tuberous roots have been studied regarding cultivation and processing (46, 50). Thus, studying techniques that improve its production system increasing quality, turns essential for a successful production.

In plant nutrition, potassium is considered an essential nutrient. It participates in enzymatic activation, protein formation, photosynthesis (21), regulation of osmotic pressure, and opening and closing of stomata (48). It is also associated with root size, shape, texture, color, flavor, acidity, nutrient transport resistance, nutritional value (38), and even market value (12). Considering this, optimizing the use of potassium constitutes an important tool in crop management, and since information related to this matter is still scarce, our study aims to evaluate the physicochemical characteristics of yacon tuberous roots as a function of different doses of potassium fertilization.

Material and methods

The experiment was located in the municipality of Alegre, in the State of Espírito Santo, Brazil, (20°47’1” S, 41°36’56” W, 680 m a. s. l.). Precipitation, relative humidity, and monthly temperature averages were obtained by automatic meteorological stations close to the experiment, using Incaper in Iúna, Espirito Santo, Brazil (20°21' S, 41°33' W, 758 m a. s. l. (figure 1). Average monthly temperatures fluctuated from 17.79 to 21.43°C, and rainfall summed 638 mm during field experiments.

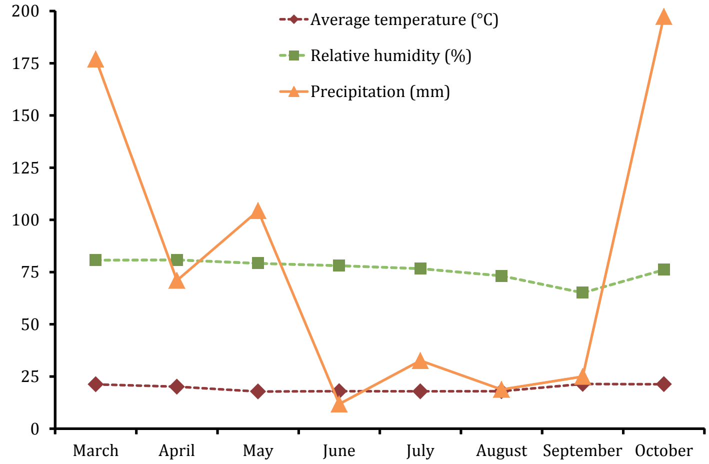


Figure 1. Monthly averages of precipitation, relative humidity, and temperature during the experimental period. Alegre-ES, 2020.

Figura 1. Promedios mensuales de precipitación, humedad relativa y temperatura durante el período del experimento. Alegre-ES, 2020.

Soil samples were collected and subjected to laboratory analysis, showing the following chemical characteristics: water pH 4.80 , P 3.95 mg dm^{-3} , K 42.00 mg dm^{-3} , Ca 0.68 $cmol_c$ dm^{-3}, Mg 0.22 $cmol_c$ dm^{-3} , Al 1.00 $cmol_c$ dm^{-3} , exchangeable bases,1.01 $cmol_c$ dm^{-3} cation exchange capacity 2.01 $cmol_c$ dm^{-3} and base saturation index 8.89%.

Soil preparation was done by plowing and harrowing at a depth of 40 cm. Liming was performed using dolomitic limestone with 96% PRNT increasing base saturation to 70%, with a period of 60 days for planting. For the propagation of yacon, 30 grams rhizophores with three to four buds were used, as recommended by Pedrosa *et al.* (2020) and planted individually on ridges with a spacing of 1.0 m × 0.5 m, as recommended by Carvalho *et al.* (2020).

The experiment was conducted in a randomized complete block design, with four replications of four different doses of potassium fertilization: 50%; 100%; 150%, and 200% of the reference value (26); and a control (soil without fertilization). The experimental plot consisted of three lines with three plants providing nine useful plants for evaluations, bordered by 2 rows and 2 extra plants. The reference value considered, at the end of 210 days after planting, was 106.8 kg. ha^{-1} of K in yacon plants (26). Final dose estimation, considering K_2O, resulted128.65 kg. ha^{-1}. A recovery efficiency of 60% for K was also considered (43). Thus, potassium chloride (KCl) doses applied were: 178.7 kg. ha^{-1}; 357.4 kg. ha^{-1}; -536.1 kg. ha^{-1} and 714.8 kg. ha^{-1}, equivalent to 50, 100, 150 and 200%. Two applications were made in coverage. The first application was performed when 80% of the plants emerged, with the first pair of leaves open (80 days after planting) and the second application was done 30 days later (110 days after planting).

Nitrogen and phosphate fertilization, were added with 382.2 $kg.ha^{-1}$ of urea and 422.6 $kg.ha^{-1}$ of simple superphosphate (26), achieving 172 $kg.ha^{-1}$ for N and 33.2 $kg.ha^{-1}$ for P (converted to 76.07 kg of P_2O_5). Phosphate fertilization was performed at planting while nitrogen fertilization was performed in coverage along with potassium. During the whole experimental period, irrigation was done by sprinkling while weeds were manually controlled.

At the end of the experiment, 210 days after planting, the plants were harvested and the roots separated and taken to the Food Chemistry Laboratory of the CCAE/UFES for chemical analyzes such as pH, soluble solids, total acidity, conductivity, turbidity, humidity, and ashes. A sample of these roots was separated for physical analysis, at the Food Science and Technology Laboratory (CCAE/UFES), where the following parameters were observed: toughness, adhesiveness, cohesiveness, index of chewability, elasticity, and gooeyness.

For chemical analysis, the roots were cut, washed, dried, and taken to a centrifuge to extract the juice, then filtered with filter paper for later evaluations. Juice direct readings of pH, electrical conductivity, and soluble solids were conducted.

Total titratable acidity was obtained by a diluted sample of the juice (5 mL of juice + 50 mL of distilled water), titrated with 0.1 mol L^{-1} NaOH solution, using phenolphthalin, according to Instituto Adolfo Lutz (2008). Acidity was calculated as a function of malic acid, the most expressive acid in yacon. Turbidity, in 10 mL of juice + 40 mL of distilled water was assessed using a turbidimeter.

Subsequently, roots from each treatment were grated and a sample was incinerated in the muffle at 550°C, until constant weight, obtaining ashes. For humidity, another set of samples was oven-dried at 105°C. Finally, root samples were standardized at 2 cm thickness and 4 cm diameter for texture analysis. Parameters were determined using the Brookfield CT3 texturometer and the TA39 needle probe, with a test speed of 2 mm s^{-1}. The target distance for drilling was set at 5 mm.

Linear regression models were tested for data processing. The analysis was performed based on average values for each treatment (four repetitions). The sum of squares, R^2 (coefficient of determination), and significance of regression coefficients constituted model parameters. Statistical analyses were performed with the open code software R (39).

Results and discussion

Turbidity and conductivity did not fit any model. The doses used did not influence root chemical variability (figure 2 AB).

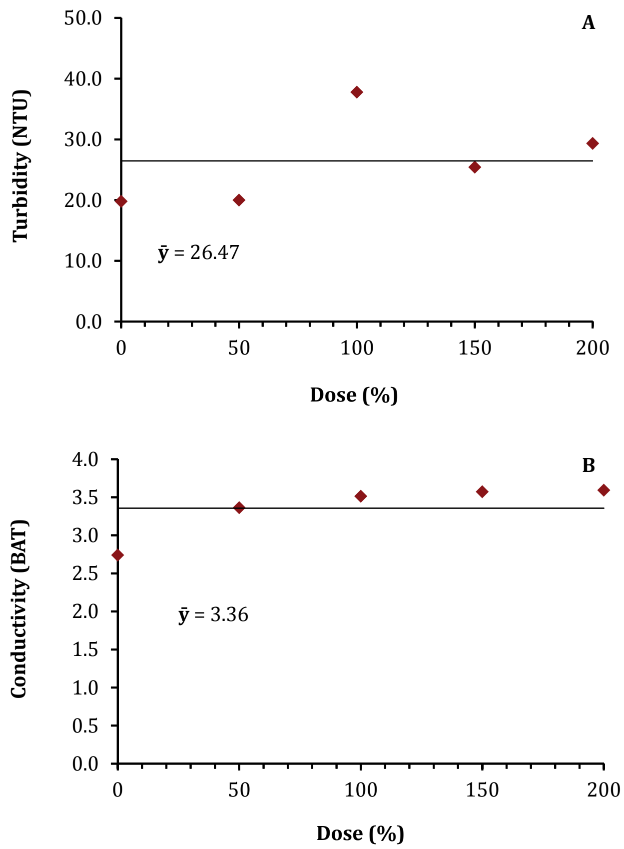


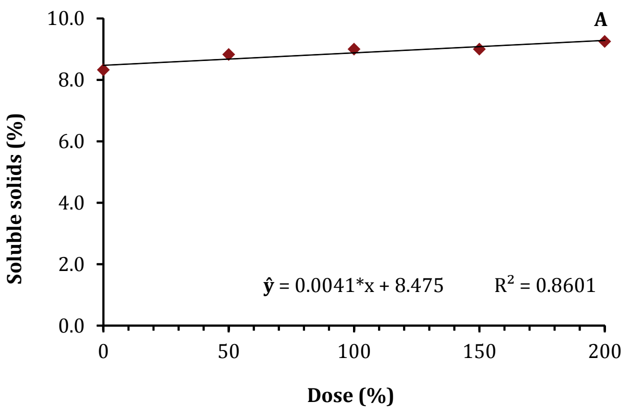
Figure 2. Turbidity (A) and electrical conductivity (B) in juice of yacon tuberous roots, according to different potassium doses. Alegre-ES, 2020.

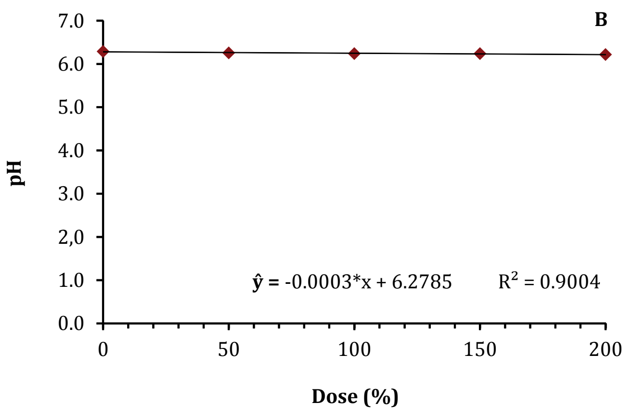
Figura 2. Turbidez (A) y conductividad eléctrica (B) en el jugo de raíces tuberosas de yacón, según las diferentes dosis de potasio. Alegre-ES, 2020.

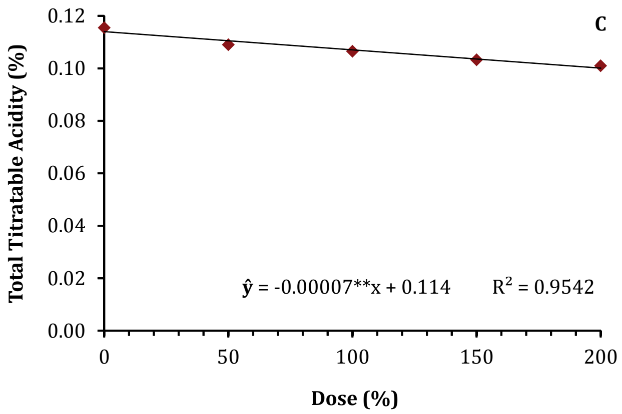
No change in juice turbidity means that the tested potassium doses did not influence insoluble solids in suspension (proteins, pectin, lipids, cellulose, and hemicellulose) in yacon roots. Insoluble solids remain in suspension after cell rupture during juice preparation (20). Juice turbidity is essential for market acceptance (8), thus, the non-alteration of this characteristic is a positive result evidencing that potassium fertilization would not cause quality losses.

Likewise, conductivity did not change, possibly due to the non-variation in turbidity, since the first is influenced by several factors, such as electrolyte concentration and temperature (27). Conductivity reflects solutions ionic behavior, and according to Icier and Ilicali (2005), can be altered by the content of insoluble solids. Several studies point out this relationship. Some authors evaluated the effect of suspended-particle size in mango juice and observed higher electrical conductivity in particle-free samples, noting that, probably, intermediate-sized particles hinder ionic movement (54). A similar result was found by Pelacani and Vieira (2003), also in mango juice and Palaniappan and Sastry (1991), in carrot juice. Both studies showed that conductivity is higher in solutions with smaller insoluble particles. Regarding the direct influence of potassium doses, Gurgel *et al.* (2010) evaluating postharvest quality of melons, obtained similar results for juice conductivity, in which regression analyzes did not fit the tested models.

Soluble solids, pH, and total titratable acidity achieved linear model fitting. Soluble solids content showed a slight increase, reaching 10% when comparing the highest tested dose with the unfertilized treatment (figure 3A). The pH, on the other hand, showed a slight decrease, although more pronounced for total acidity, which decrease by 17% with the highest potassium dose (figure 3 BC). Increased total soluble solids with the highest availability of potassium occur as a result of a potassium-mediated favored carbohydrates formation and translocation (22). Potassium influences plant water transport stimulating solute storage in organs such as seeds, tubers, roots, and fruits (25, 38).







Significant at the level of 5% (*) and 1% (**) by Student t-test.

Significativo al nivel del 5% (*) y 1% (**) por la prueba t de Student.

Figure 3. Soluble solids (A), pH (B), and total titratable acidity (C) in juice from yacon tuberous roots according to different potassium doses. Alegre-ES, 2020.

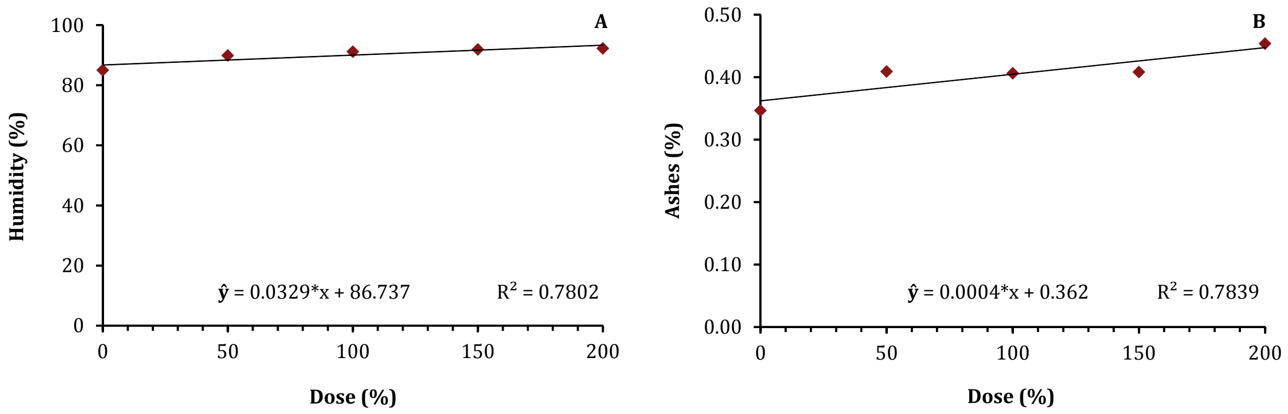
Figura 3. Sólidos solubles (A), pH (B) y acidez total titulable (C) en jugo de raíces tuberosas de yacón según diferentes dosis de potasio. Alegre-ES, 2020.

The results show a contribution of potassium fertilization for yacon roots quality evidenced by increased sugar content (main component of soluble solids), vitamin C, other acids, and some pectins, as previously mentioned (7), rising the possibility for this product´s market better acceptance.

The observed subtle decrease in acidity (pH and total acidity) may have occurred after a greater conversion of sugars (higher levels of soluble solids) and degradation of organic acids (19, 35), possibly after accelerated root maturation, given greater availability of potassium. Similar results were observed by Barreto *et al.* (2020) with peach, Delgado *et al.* (2004) with grapes, and Veloso *et al.* (2001) with pineapple, who reported fruit ripening anticipation, favored by increasing available potassium.

In fruit ripening, higher sugar levels cause sharp neutralization of organic acids, making the fruit less acidic and sweeter (14). This possibility was also pointed out by Silva *et al.* (2018) for yacon roots, after observing a reduction in acidity at an established stage of life-cycle ending, then considered as the proper harvest time for sweeter roots, an essential characteristic for palatability and better market acceptance.

Regarding humidity and ashes, an increasing linear fit showed that for the highest potassium dose (200%) both variables increased 8 and 22%, respectively (figure 4).



Significant at 5% (*) by Student t-test.

Significativo al nivel del 5% (*) según la prueba t de Student.

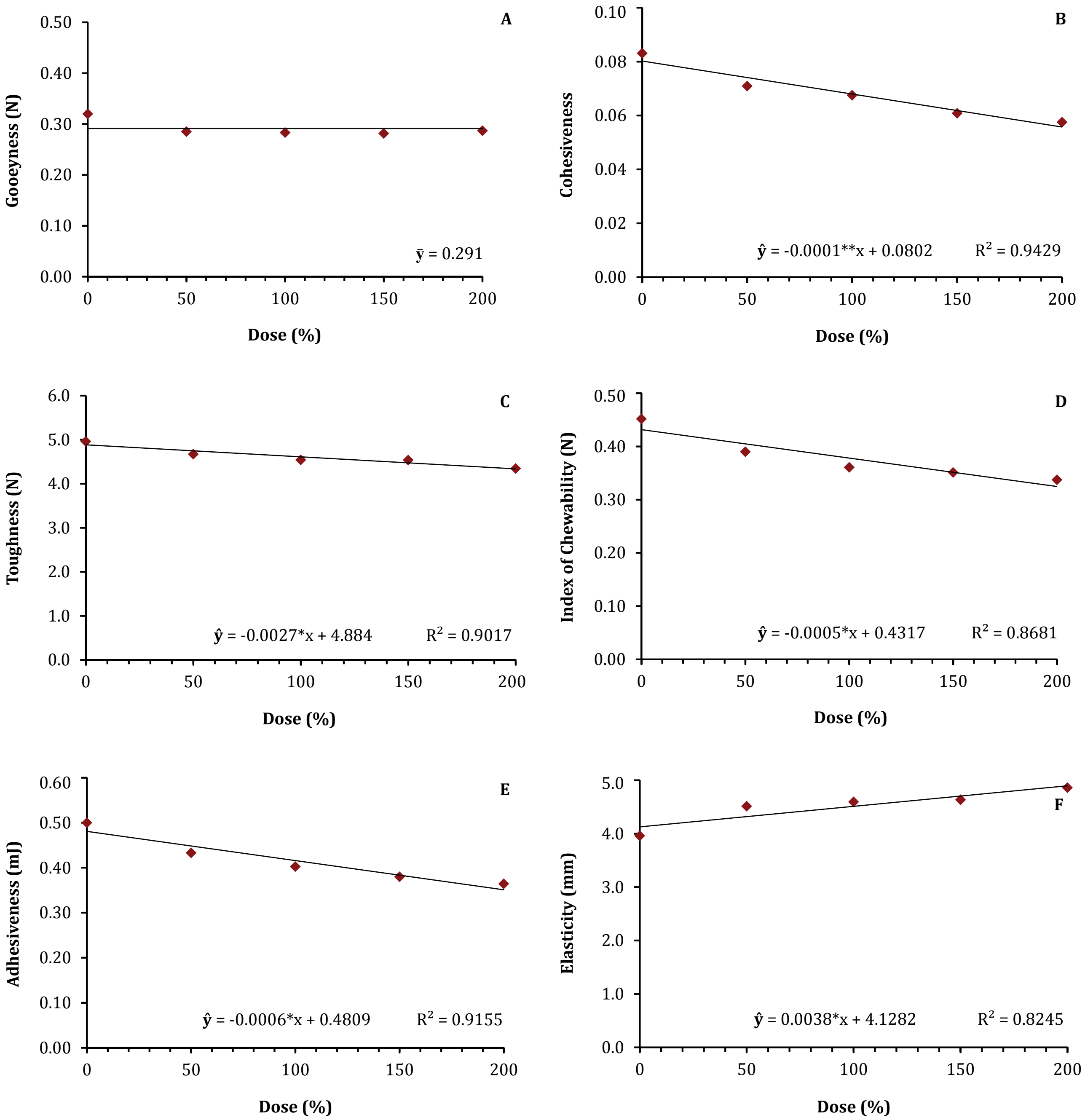
Figure 4. Humidity (A) and ashes (B) in yacon tuberous roots, according to increasing potassium doses (Alegre-ES, 2020).

Figura 4. Humedad (A) y cenizas (B) en raíces tuberosas de yacón, según las diferentes dosis de potasio (Alegre-ES, 2020).

This increased humidity in yacon roots means high water content and low energetic food, both high-quality standards (41). Humidity may vary depending on a range of interactive factors, including field conditions, planting, harvest, and fertilization (34). Similar results in potato tubers obtained by Quadros *et al.* (2009) pointed out that the highest potassium dose provided higher percentages of humidity. However, considering post-harvest conservation, significant higher moisture contents may cause greater difficulty in preserving the product (44, 47). Still, the resulted increase (8% for the highest dose compared to the control) turns irrelevant, as with fast and adequate storage (dehydration preventing conditions) (49), no significant losses should complicate commercialization.

The higher levels of ashes are related to increasing root mineral contents after potassium fertilization. This was already observed by Quadros *et al.* (2009) with common potatoes. Additionally, Oliveira *et al.* (2015) state the importance of potassium supply, through balanced nutrition, since product quality (tuber, rhizomes, and tuberous roots), may vary according to the performed fertilization.

Regarding texture analysis, only gooeyness values resulted independent of potassium doses. For cohesiveness, toughness, index of chewability, and adhesiveness, increasing potassium doses resulted in decreasing values. Elasticity, in turn, increased with increasing doses (figure 5).



Significant at 5% (*) and 1% (**) by Student *t*-test.

Significativo al nivel del 5% (*) y del 1% (**) según la prueba t de Student.

Figure 5. Gooeyness (A), cohesiveness (B), toughness (C), index of chewability (D), adhesiveness (E), and elasticity (F) of yacon tuberous roots, as a function of increasing potassium doses (Alegre- ES, 2020).

Figura 5. Pegajosidad (A), cohesión (B), tenacidad (C), índice de masticabilidad (D), adhesividad (E) y elasticidad (F) de las raíces tuberosas de yacón, en función de diferentes dosis de potasio (Alegre- ES, 2020).

Gooeyness is related to the force required to disintegrate food, by dissociating its mass. For Bolzan and Pereira (2017), it is associated with toughness and cohesiveness. However, in this case, despite the linear decrease in cohesiveness and hardness with the increasing potassium doses, no gooeyness alteration was evidenced in the analyzed yacon tuberous roots. That is, yacon roots can withstand rupture (cohesiveness measure), and demand less strength to be obstructed (toughness measure) (1). In this sense, in a prior sensory analysis with the application of potassium doses, the roots became softer, requiring less strength (25% less with the highest dose of potassium) to be squeezed between the molar teeth at the first bite (14). The same was noticed for chewability (around 24% reduction of needed strength with the highest dose of potassium) (9). These results evidence gains in sensory quality of yacon roots fertilized with potassium.

Decreased adhesion occurred after increasing humidity, which, according to Rahman and Al-Farsi (2005) are inversely proportional characteristics. In sensory terms, increasing potassium doses, eases food ingestion, due to lower adherence strength (reduction of around 28% with the highest dose of potassium), increasing sensory quality.

The resulting root-increased elasticity was expected since this characteristic is inversely proportional to hardness, cohesiveness, and chewability (42). This greater elasticity (18% in the maximum dose) contributed to root quality.

Finally, texture constitutes an important factor and quality criterion for the sensory acceptance of food (6). Thus, the results obtained show that potassium fertilization improves both physical and chemical characteristics of yacon roots.

Conclusion

Potassium fertilization improved both physical and chemical characteristics of yacon roots, The best results were observed with the maximum applied dose (357.4 $kg.ha^{-1}$ of KCl).

With the application of the maximum dose, highest levels of soluble solids (9.25%), moisture (92.24 %), ash (0.454 %) and elasticity (4.86 mm) and lower acidity (0.101 %) and pH (6.22) were achieved, in addition to lowest chewability indexes (0,337 N), hardness (4,35 N), cohesiveness (0,058) and stickiness (0,364 mJ). Such results add greater value to the final quality of the roots.

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