Nutraceutical, thermophysical and textural characteristics of papaya (*Carica papaya* L) and incidence for post-harvest management

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**ABSTRACT**

Papaya fruit is of great importance to local trade. The objective of this research was to evaluate the textural, thermophysical and nutraceutical characteristics (Total phenolic and vitamin C) of fruit cultivated in the Colombian Caribbean in the post-harvest period. Five ripening stage levels were used as a treatment factor. The puncture method was used to measure the firmness of the shell (N) and firmness of the pulp (N) using uniaxial compression tests to measure the deformability modulus (MPa) and elasticity limit (MPa). The thermophysical parameters: thermal conductivity (k), density (ρ), diffusivity (α) and specific heat (Cp) were calculated using the adjusted math model. The shell firmness decreased from ripening stage one to ripening stage five. The total phenolic content did not conform to a certain model and presented an inversely proportional relationship with the ripening stage. The vitamin C content was directly proportional to the ripening stage and was adjusted to a double quadratic behavior with a coefficient of determination.

1. Introduction

Fruits such as papaya cannot be studied as liquid fluids; therefore, textural studies consider textural and firmness variables within mechanical properties. Important calculations include the deformability module, which is characteristic of each material, independent of the shape and size of the sample, and is a strength indicator when food is subjected to tension or compression, interpreted as the maximum force that can be applied to the material without breaking it. Among the models used to predict thermophysical properties, the most widely used mathematical model for thermophysical properties is the one developed by Choi and Okos (1986), based on the temperature and the composition of the food moisture, protein, fat, fiber, carbohydrates and ash. Fruit and vegetable thermal properties are needed to calculate the cooling or heating speed and are required in important operations such as blanching, pasteurization, evaporation, frying, refrigeration, freezing, sterilization and drying, which are common in foods where there are mass and energy transfers (Alvis et al., 2012; Alvis et al., 2015; Sadeghi et al., 2012.) The nutraceutical capacity of a fruit is determined by important health components, such as vitamins and phenolic compounds. These components eliminate free radicals and reduce oxidative stress in biomolecules. They can have a positive impact on the prevention of diseases such as coronary origin disease or various types of cancer (Morazina et al., 2011) (Padilla et al., 2008). The objective of the present study was to evaluate the firmness in shell and pulp, the deformability module and the elasticity module as a determining factor of the “Tainung” papaya packaging process, developed by the association of papaya farmers Alto Sinú (APPALSI in the municipalities of Valencia and Tierralta, Cordoba-Colombia). In addition, thermophysical properties were evaluated as a reference point for the pulp agro-industrialization processes. The evaluation of the total phenols content and vitamin C content obtained important information for the antioxidant potential present in the Tainung papaya in relation to the ripening stage, highly relevant data for the use of fruits in mass-consumption foods (dehydration, crystallized fruits, preserves, and fresh consumption, among others), taking advantage of functional properties.

2. Materials and methods

Tainung Hybrid (F1) papaya fruits (hermaphrodite, export type) were harvested from one-year transplanted plants without damage, bruises or rot. Five (5) stages of maturity were taken with average sizes and weight, defined as 1320 g and grown by the association of papaya producers Alto Sinú (APPALSI) in the municipalities of Valencia and Tierralta-Cordoba, Colombia during the months of May to June of 2019. Samples were randomly selected from containers at the collection site where fruits from

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different associated farmers were located, ensuring randomness in the sampling. The tests and measurements were carried out in the agro-industrial processes laboratory of the University of Córdoba, Colombia, located at 8°40’26”W latitude and -75°42’36.98”W longitude, with an average temperature of 27.4 °C.

2.1. Mechanical characterization of Tainung papaya fruits

The degree of maturity was established from the color of the fruit peel. For the texture test, an XTPlus Stable Micro Systems® texturometer with a 2 mm diameter cylindrical probe was used. The penetration rate was adjusted to 5 cm min⁻¹ at an average ambient temperature of 27.4 °C. Figure 1 shows the maturity grades chosen for the tests.

To perform the fruit compression experiments, the geometry of pulp cubes with an edge size of two centimeters was used. The compression plate used was 75 mm and was placed at a distance of 5 mm from the cubes with a speed of 10 mm s⁻¹. The variables obtained from this test were the force measured in Newton and deformation measured in millimeters to reach the elastic limit (maximum tension that a material can withstand without showing permanent unit deformation by completely eliminating the origin of the tension in N mm⁻²). For all studies, a completely randomized experiment design was used, with ripening stage as the only factor at five levels. Ten replicates were carried out for each test. For the different variables measured in the textural analysis, the mean and standard deviation were determined. STATGRAPHICS Centurion XVI® software was used for analysis of variance and Tukey’s test of means (p ≤ 0.05) from the data obtained.

2.2. Determination of the thermophysical properties of fresh Tainung papaya

The determinations were made with harvested and maintained fruits at an average temperature of 27.4 °C (Room temperature of the place). Five fruits were taken for each maturity stage for the measurements.

The calculated thermophysical properties were the thermal conductivity (k) measured in W m⁻¹ °C⁻¹, the thermal diffusivity (α) measured in m² s⁻¹, the density (ρ) measured in kg m⁻³, and the specific heat (Cp) measured in kJ kg⁻¹ °C⁻¹. To perform the measurement, the Tainung papaya bromatological composition was analyzed using the methods described by Bernal (1993): Moisture with the 930.15/90 method of the A.O.A.C.; Ash with the 942.04/90 method of the A.O.A.C.; Crude protein with Method 955.04/90 of the A.O.A.C.; Raw fiber: with Method 920.39/90 of the A.O.A.C.; and Carbohydrates were determined with the difference of the other analyses.

A completely random design was applied, where the five papaya ripening stages, with a total of five repetitions per measurement, were considered as treatments, with a total of five replicates for each maturity stage. Consequently, the analysis of statistical assumptions for parametric tests and the observation of significant differences between the results measured at 95% (p ≤ 0.05) confidence was performed. The mathematical model developed by Choi and Okos (1986) to predict these properties was used, based on temperature and composition of the food, such as moisture, protein, fat, fiber, carbohydrates and ash. These data were processed with DEPROTER® to determine the thermophysical properties.

2.3. Evaluation of the total phenolic content and the vitamin C content in the Tainung papaya pulp

The determinations were made with harvested and maintained fruits at an average temperature of 27.4 °C. The same samples (five fruits for each maturity grade) were used for all analyses.

The total phenolic content was determined by measuring the Folin-Ciocalteu index, method AOAC 9.11–9.112. The total phenolic content was determined using the Folin–Ciocalteau assay: 100 μL of test sample, diluted appropriately with water or gallic acid standard, were mixed with 500 μL of Folin–Ciocalteau reagent and 2 mL of 10% sodium carbonate solution, and distilled water was added to reach a final volume of 10 mL. The mixture was stirred and kept for 30 min at room temperature in the dark. The absorbance was measured at 725 nm against the blank. Aqueous solutions of gallic acid (between 0 and 100 mg L⁻¹) were used for the calibration. The results were expressed as mg of gallic acid equivalents (GAE) per 100 g. The determination of the vitamin C content was made with AOAC titration method 967.21 and with the colorimetric method using 2-Nitroaniline standardized in the Department of Chemistry, Universidad Nacional, Bogotá. The data determined the relationship between the total phenolic content and the vitamin C content with the ripening stage at a level of significance of 95% (p ≤ 0.05).

3. Results and discussion

3.1. Mechanical characterization of Tainung papaya fruits from penetration tests

The initial firmness of Tainung papaya fruits harvested at ripening stage 1 was 58.65 ± 0.11 N in the peel. Figure 2 shows the decrease in the firmness of fruits preserved at room temperature (27.4 °C) with
The differences between the firmness of green harvested papayas (stage 1) and papayas when ripe for consumption (stage 4 and 5). Table 1 shows the values of firmness in the shell and pulp for the five evaluated ripening stages.

The data showed a noticeable decrease in firmness during ripening stages 4 and 5, which represented a storage time from 6 to 9 days at 27.4°C. There were significant differences between the firmness in the shell and pulp for all ripening stages. The lines below the X-axis showed the adhesiveness when the punch was removed from the fruits that were analyzed. Adhesiveness was not considered as a study response in this study. Loss of firmness is favored by the action of enzymes, such as hydrolases, induced by respiration rate and ethylene production, which cause degradation of peptic substances and hemicelluloses (Thumdee et al., 2007). The decrease of the resistance when advancing the ripening stage is related to the loss of elasticity and viscosity of the pulp from the conversion of starch to sugars. In other firmness studies, values of 70 N in ripening stage (1) have been obtained, with 10 N in the ripening stage (5) for Maradol variety papaya (Krongyut et al., 2011). For the Golden variety, firmness values less than 20 N in stages 4 and 5 of ripening have been reported, similar to the firmness values presented by the Tainung variety in the present study for stages (4 and 5). Loss of firmness is a condition that would affect the possibility of exporting fruits, and given the limited scope for marketing in the target markets, stages 1 and 2 are more acceptable for transport. Sañudo et al. (2008) reported firmness values of 140 N in ripening stage (0) and 115 N for ripening stage (1), while ripening stage (5) reached values less than 15 N in the Maradol variety cultivated in Nayarit, Mexico. Maradol papaya and materials grown in Yucatan, Mexico, such as Jibara, Azteca, Sensation, Intenzza, and Siluet, have been listed by Santamaria et al. (2015) and Lobo et al. (2012), with values of 9.3N, 8N, 7.6N, 7.8N, 6.2N and 6.1N for consumer ripening firmness, respectively. Consequently, Tainung papaya is an intermediate firm fruit when compared with other varieties in stages (1 and 2), a stage for fruit transport. These measurements are parameters to be considered when selecting fruit packaging and disposal for transport and marketing.

### 3.2. Mechanical parameters for studying firmness and rupture force compression

The deformability and elasticity limit module showed significant differences between the initial ripening stages and the ripening consumption, while ripening stages (4) and (5) showed no statistical differences. The deformability module analysis was determined from the stress curve (MPa) and relative deformation (%) shown in Figure 3. The values obtained from the strain curves are shown in Table 2. The strain modulus calculation showed values of 1.81·10^{-3} ± 0.12 MPa at maturity stage 1, with a decrease to 5.22·10^{-4} ± 0.015 MPa at maturity stage 5. This effect was attributable to the loss of rigidity of the fruits during its ripening process. The deformability module, suggested as a measure of fruit firmness, and the elasticity limit show the maximum load that fruits can bear during storage under static loads (Chen et al., 1987). In other plants, such as yam, deformability module values of 1.7 MPa are average, while for sweet potatoes, values of 4.39 MPa are average (Alvis et al., 2015). Fruits with higher fiber content have higher strength and higher deformability module values (Negrin et al., 2013). In guava fruits, values of 3.51 MPa were obtained in green fruits, and 1.22MPa values were observed for consumption, with records of 0.91MPa for over-ripe fruits (Fernández et al., 2013), as reported in studies on tomato variety Roma with deformability modules from 1.14 MPa to 1.87 MPa.

The elasticity limit calculated for the Tainung papayas ranged from 7.31·10^{-2} ± 0.0021 MPa at ripening stage 1–2.39·10^{-2} ± 0.0022 MPa at ripening stage (5). This parameter has been reported in fruits such as guava with values of 0.22 MPa at physiological ripening and sourloss with values of 0.018 MPa in green fruit and 0.0013 MPa for ripe fruit (Marquez, 2009; Yam et al., 2009). The strain curve provides very specific mechanical indices of food, such as the elastic limit, the plastic range and the break point. From the axial compression tests, it was evidenced that papaya fruits present biocedance from maturity stage 3 to stage 5. According to Mohsenin (1972) this characteristic is associated with the non internal cellular rupture of the fruits. According to these results, the transport of Tainung papayas in stages (1) and (2) is feasible by accommodating fruits vertically or horizontally for the limits calculated in the firmness and compression tests.

### 3.3. Determination of the thermophysical properties of Tainung variety papaya

The results of the bromatological analysis of the Tainung papaya can be seen in Table 3.

From the data of the analysis of physicochemical components, the data of the thermophysical properties Table 4 were obtained based on the mathematical models of Choi and Okos (1986).

Figure 4 shows the behavior of the thermophysical properties of the Tainung papaya. The thermal conductivity did not present significant variation with the advance of the ripening stage, where the density increased, the thermal diffusivity decreased, and the specific heat maintained little variation, tending to be a little lower in ripening stage 5. Slow heat penetration during heating or cooling in pulp processing can cause undesirable changes in quality, particularly if the product is heated or cooled in large containers. These measurements are of great importance as papaya is widely used in the Sinú region to prepare canned fruits. Therefore, it is important that the thermal conductivity or thermal

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**Table 1. Firmness analysis (N) in Tainung papaya.**

| Firmness (N) | Ripening Stage |
|-------------|----------------|
| Shell       | 1   | 2   | 3   | 4   | 5   |
|             | 58.65 ± 0.11 | 41.84 ± 0.08 | 33.34 ± 0.10 | 21.45 ± 0.03 | 19.7 ± 0.10 |
| Pulp        | 32.6 ± 0.10 | 19.83 ± 0.05 | 10.42 ± 0.11 | 2.93 ± 0.07 | 2.63 ± 0.10 |

For each variable, means with the same letter in each row are statistically equal (Tukey p ≤ 0.05).

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**Table 2. Results of the deformability module (MPa) and the elasticity limit (MPa) for Tainung papaya.**

| Ripening Stage | Deformability module (MPa) | Elasticity limit (MPa) |
|----------------|----------------------------|------------------------|
| 1              | 1.81·10^{-3} ± 0.12         | 7.31·10^{-2} ± 0.0021  |
| 2              | 0.855·10^{-3} ± 0.015       | 5.06·10^{-2} ± 0.0024  |
| 3              | 0.799·10^{-3} ± 0.013       | 4.30·10^{-2} ± 0.0032  |
| 4              | 0.688·10^{-3} ± 0.012       | 2.46·10^{-2} ± 0.0026  |
| 5              | 0.522·10^{-3} ± 0.015      | 2.39·10^{-2} ± 0.0022  |

For each variable, means with the same letter in each column are statistically equal (Tukey p ≤ 0.05).
diffusivity of these products is known with reasonable accuracy (García, 2009). Specific heat and thermal conductivity generally tend to be linearly dependent on water content and temperature, while density does not follow that same tendency (Moraga, 2008).

According to the studies of thermophysical properties carried out by Guevara et al. (2010) in papaya pulp from the Maradol variety, average values of 0.755 W m⁻¹ °C⁻¹ are indicated for thermal conductivity, with 3.73 kJ kg⁻¹ °C⁻¹ for specific heat and 991 kg m⁻³ for density. The processing of papaya pulp in the form of puree with a total soluble solid content between 10 and 25 °Brix, as analyzed by Tansakul et al. (2010), showed an average value of 0.685 W m⁻¹ °C⁻¹ for thermal conductivity, 4.092 kJ kg⁻¹ °C⁻¹ for specific heat and 1.650×10⁻⁷ m² s⁻¹ for thermal diffusivity. Ikegwu and Ekwu (2009) reported data on the thermal properties of fruits such as pear with 0.567 W m⁻¹ °C⁻¹, 1.520×10⁻⁷ m² s⁻¹, 3.82 kJ kg⁻¹ °C⁻¹, melon with 0.616 W m⁻¹ °C⁻¹, 1.480×10⁻⁷ m² s⁻¹, 4.05 kJ kg⁻¹ °C⁻¹, mango with 0.562 W m⁻¹ °C⁻¹, 1.390×10⁻⁷ m² s⁻¹, 3.78 kJ kg⁻¹ °C⁻¹, guava with 0.547 W m⁻¹ °C⁻¹, 1.360×10⁻⁷ m² s⁻¹, 3.70 kJ kg⁻¹ °C⁻¹, and bananas with 0.498 W m⁻¹ °C⁻¹, 1.500×10⁻⁷ m² s⁻¹, 3.45 kJ kg⁻¹ °C⁻¹.

According to Peleg (1993), thermal diffusivity is directly proportional to temperature and is linked to thermal conductivity although, in many foods, the effect of temperature may be less pronounced. In addition, it is an indicator of the capacity of biological material to store heat once it is heated (Adekunle et al., 2013; Fricke and Becker, 2002). Based on these references, Tainung papaya grown by the APPALSl association in the Department of Córdoba has similar values of thermophysical properties, which are between the averages of other tropical fruits. When considering bromatological composition, in relation to measured thermophysical properties, density may be affected by temperature and water content. According to Acurio et al. (2015), an increase in density in the ripening stage can be explained by the increase in soluble solids of fruits, in a range of 0–22 °Brix, the fact that specific heat is linked more to the water content than to the temperature, and the fact that thermal conductivity can be directly proportional to temperature and water content.
The effect of temperature is much greater. Consequently, thermal diffusivity may be directly related to water content and temperature although the effect of water is greater as indicated by Giraldo et al. (2010; Alvarado (1994). Another important aspect to consider is porosity although in Tainung papaya, it is not a relevant characteristic. This effect can influence slight changes in diffusivity proportionally even at the microscopic level (Machado and Velez, 2008). The thermal properties of the Tainung papaya cultivated in the Department of Córdoba must be known as a reference of the plant product, considering the heterogeneity presented by food matrices, as well as the influence of cultivation conditions. The agroindustrialization and the manufacture of new products requires knowledge on the functional data of food. The study of predictive models for thermal properties is needed to achieve these purposes.

3.4. Evaluation of the total phenolic content and the vitamin C content in the pulp of Tainung papaya

3.4.1. Evaluation of the vitamin C content

The evaluation of the vitamin C content in the Tainung papaya pulp is shown in Figure 5, with a slight increase with respect to the ripening stage. The pulp averaged 60.2 ± 0.96 mg/100 g (fresh weight) for ripening stage 5 and 59.08 ± 0.91 mg/100 g (fresh weight) for ripening stage (1). Significant differences in vitamin C content were found for ripening stage (3, 4 and 5). The data conformed to the double-square model shown in Eq. (1). With a coefficient of determination R² of 0.96.

\[
\text{Vitamin C} = \sqrt{3483, 94 + 5, 85085^2} \ \text{mg/100 g} 
\]  

(1)

In papaya, unlike most fruits, there is an increase in vitamin C content as the fruit develops (Lobo, 1995). The vitamin C content in papaya showed an increase in similar research, as indicated by Oliveira et al. (2010) for Tainung 1 papaya cultivated in Baraúna-Brazil, with average values of 60 mg/100 g to 65 mg/100 g. Similarly, Souza et al., (2005) reported values of 76.7 ± 1.21 mg/100 g. There are also records of 55 mg/100 g (Lobo, 1995), 60.9 mg/100 g, as well as contents of 45.3 mg/100 g in wild papaya, 71.3 mg/100 g for (Tainung 1), 154 mg/100 g found in papaya cultivars of Santa Amalia-Cuba, and values of 68.9 ± 2.38 mg/100 g in Maradol variety papaya (Rodriguez et al., 2014).

The increase in vitamin C content in the higher ripening stages can also be explained by the acidity of the fruit. This behavior facilitates the availability of other organic acids as a source of energy, which are used in oxidative processes instead of ascorbic acid. Vitamin C is present in many availability of other organic acids as a source of energy, which are used in oxidative processes instead of ascorbic acid. Vitamin C is present in many antioxidants (Agular et al., 2015). The variation in vitamin C content among the different ripening stages can be related to the functionality of this phytoneutrient, which is important for the division, differentiation and development of the fruit. Figure 6 shows a comparison between the vitamin C contents found in Tainung papaya in this study and other vegetables in mass consumption; the increase in the level of sugars in the tissues of the fruits results in an increase in ascorbic acid since it is synthesized from hexoses. It is important to note that the vitamin C content can be influenced by elements of solar radiation, climate, and temperature. Assessing the vitamin C content at different ripening stages is important for analyzing the stage of development of harvested fruit, showing the nutritional benefits of the pulp, which is consumed in ripening stage 4 and 5 in Siru and used in ripening stage 3 in sweets and dehydrated products. The data and the comparisons between the vitamin C contents for each ripening stage also represented an important measurement for future research on cultivation conditions and even for monitoring or researching ripening conditions, fruit transport and consumption (Correa et al., 2012; Moreiras et al., 1995).

3.4.2. Evaluation of the total phenols content

There were significant differences between the total phenolic content values for each ripening stage. The results of the determination of total phenolic content in Tainung papaya pulp are shown in Figure 7. The decrease in phenolic content observed from stage 1 with 342.4 ± 0.93 mg/100 g gallic acid equivalent (GAE) to stage 5 with 240.7 ± 1.1 mg/100 g gallic acid equivalent may have been related to the high oxidative metabolism that occurs as the result of the appearance of reactive singlet oxygen species. The extraction method using methanol-water may also have a lower impact on the extraction of phenols than methanol-acetone mixtures (Lu and Foo, 1999). The decrease in phenolic content with the ripening stage can also be associated with the primary antioxidant effect of these phytonutrients (Olaya et al., 2012).

When contrasting the evidence with papaya cultivated in Peru, the total phenolic concentration values were 167 ± 0.3 mg/100 g gallic acid equivalent for papaya and 57 ± 0.2 mg/100 g gallic acid equivalent for tropical papaya (Repo and Encina, 2008). The total phenolic content of Tainung papaya is an intermediate level, as compared to the content of other fruits and vegetables. Figure 8 shows a comparison between the total phenolic content of Tainung papaya and other fruits according to antioxidant capacity studies in Colombian fruits (Zapata et al., 2014; Calderón et al., 2011; Cárdenas et al., 2015).

The total phenolic content in fruits can be associated with genetic diversity, ripening stage, climate, temperature, light intensity, use of fertilizers and storage conditions (Vasco et al., 2008). The antioxidant capacity of fruits can be directly related to the total phenolic content, as reported by Prior et al. (1998), highlighting a high positive correlation between these two parameters. In addition, ascorbic acid and carotenoids also influence measurements, Contreras et al. (2010). The biosynthesis of phenolic compounds is associated with the action of the enzyme phenylalanine ammonia lyase (PAL), which acts in the last stages of fruit growth and favors the concentration of antioxidants at the beginning of maturation. The importance of analyzing the total phenolic content in Tainung papaya cultivated in the Department of Córdoba is related to the capacity of these phytonutrients to restore cells lacking the P53 gene, the gene responsible for apoptosis and the control of cell proliferation responsible for cancer. In general, phenolic acids have anticancer activity. The
comparative advantages for the market include relevant data for the technical data sheet and promotion of properties of fruit consumption, as well as monitoring phenols in agro-industrial transformation processes.

4. Conclusions

The maturity stage of papaya is conducive to the appearance of biocedence from ripening stage 3 to stage 5. Tainung papaya fruit has a behavior similar to that of viscoelastic materials, due to the loss of stiffness evidenced by the decrease in the modulus of deformability and yield strength as the maturity stage increases. The ripening stage of the Tainung papaya significantly affects the thermophysical properties. The pulp of Tainung papaya requires a heat distribution that is similar to other tropical fruits, such as mango or guava, and that is slightly less than other known papaya varieties, which should be taken into account for the choice of equipment and heat sources. The vitamin C content increased with the progression of ripening stage. This result confirmed the importance of maintaining fruits in proper storage conditions to avoid oxidation of the phytonutrient. The vitamin C content in Tainung papaya is comparable to other fruits, such as guava or strawberries, which is considered high. This information is a plus for marketing fruits within the framework of exported, health products. The Tainung papaya has an intermediate level for the total phenolic content, which is remarkable at the time of marketing. The evaluation of the content of total phenols and vitamin C obtained important information on the antioxidant potential in Tainung F1 papaya in relation to the ripening stage, which is highly relevant data for use in mass-consumption foods (dehydration, crystallized fruits, preserves, and fresh consumption, among others), taking advantage of the functional properties. The present study responded to the need for a production chain in the Department of Córdoba by demonstrating the need to characterize “Tainung” variety papaya production and implement a quality management system and pot-harvest management for control, good agricultural practices, product traceability, strengthening post-harvest logistics, standardization of fruit quality, and staff training.
Declarations

Author contribution statement

Guillermo Arrazola Paternina: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Fernando Villadiego Luna: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Armando Alvis Bermudez: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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No data was used for the research described in the article.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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