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**ORIGINAL ARTICLE**

# Physicochemical Characteristics of a Greek Yogurt Sweetened with Sucralose and Containing Araticum or Mangaba Fruit Pulp as Additives

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**Abstract**

Greek yogurts with exotic fruits and non-sucrose sweeteners can be suitable for patients with diabetes. This study aimed to evaluate the changes in the physicochemical properties and stability of a Greek yogurt formulated with sucralose as a sweetening agent. The ingredients used to formulate this dairy product included milk, sucralose, pasteurized araticum or mangaba pulp. Physicochemical analyses of the Greek yogurts were carried out every seven days by measuring their pH, titratable acidity, color (L*, a*, and b* parameters) and water activity. The total phenolic content and texture (hardness, adhesiveness, compressibility, and cohesiveness) were assessed at days 7 and 28. Contents of moisture, ash, protein, lipid, glucose-reducing sugars, and lactose-reducing sugars were evaluated after 24 h of storage. In conclusion, mangaba and araticum fruit could be used as flavoring agents for Greek yogurt and sucralose addition had no effect on its physicochemical characteristics.

***Practical application***

The yogurt developed in this study was prepared using regional fruit pulp and sucralose, a sweetener consumed by people with sucrose restriction. The fruits used have an exotic and accentuated flavor and can be found in rural communities, which helps preserve these species in the Cerrado. Using these fruits in yogurt formulation and replacement of sucrose by sucralose diversifies the production of dairy products with low sugar content, making this yogurt suitable for diabetic patients and helping in preserving their health.

**Keywords:** *Annona crassiflora*, *Hancornia speciosa*, dairy product, storage.



## 1. Introduction

Strained yogurt, also known as Greek yogurt can be produced with different types of milk. The physicochemical parameters of strained yogurt vary with an average of 22–25% total solids, 5.5–10% fat, up to 12% protein, 3.0% lactose, 0.7% ash, and approximate pH 3.7 (Kirdar & Gun, 2002).

Increasing awareness of diseases such as diabetes and obesity associated with consumption of high-fat and high-sugar foods have encouraged discussions about the health benefits of Greek yogurt. This has increased the demand for yogurt varieties with reduced, eliminated, or replaced fat and sugar (Jaoude *et al.*, 2010). Production of Greek yogurts with restrictions on ingredients such as fats and sucrose is challenging because these components play a key role in improving the physicochemical and sensory properties of foods. However, addition of synthetic sweeteners is not well accepted by some people due to an unfavorable residual flavor and a perception of change in the food properties (Haque & Aryana, 2002).

Substitution of sucrose with synthetic sweeteners is not always appropriate because of its role as a flavoring, preservative, and texturizing agent (Haque & Aryana, 2002).

Although sugars added to yogurt formulations play an important technological role (Haque & Aryana, 2002; Januário *et al.*, 2017), studies are ongoing globally to explore ways to reduce or completely replace sucrose with sweeteners and their combinations such as aspartame and maltodextrin (Haque & Aryana, 2002), aspartame (Chakraborty *et al.*, 2017), vegetable and fruit juices (Drewnowski *et al.*, 2004; Januário *et al.*, 2017), and saccharine, acesulfame-K, and aspartame (Yaqub *et al.*, 2018).

Different artificial sweeteners present different properties, equi-sweetness, and sweetening power according to their concentration and the temperature of the food to which they are added (Cardoso *et al.*, 2004). Accordingly, different methodologies such as estimation of magnitude and graphical presentation of data using the "power function" or Steven's Law are applied to estimate the sugar concentration and then to use a sweetener with sweetening power similar to sucrose (Cardoso *et al.*, 2004; Souza *et al.*, 2013). Sucralose is a sweetener with a pleasant taste, high sweetness intensity, and a large possibility of application in foods including yogurts, as it remains stable at high temperatures (Aditivos & Ingredientes, 2014).

Fruits help enrich dairy products with sugars, fibers, and nutrients and improve their satiety (Drewnowski *et al.*, 2004). They also provide an option for consumers who desire to diversify their diet and to those who enjoy fruits with exotic flavors found in certain regions of the country. Replacement of processed sugars and fats with fruits has also been recommended by health experts as yogurt is appreciated by different consumer groups (El-Abbadi *et al.*, 2014).

Fruits such as araticum (*Annona crassiflora*) and mangaba (*Hancornia speciosa*), from the state of Mato Grosso belonging to the Brazilian Savannah or Cerrado, have high levels of simple sugar and minerals contents; therefore, use of their pulps in dairy products can make them healthier (Arruda *et al.*, 2016). Furthermore, they have an exotic and remarkable flavor that justifies their incorporation into dairy products formulated using sweeteners (Bett *et al.*, 2017).

According to Miele *et al.* (2017), replacing sugar with sweetener can modify the rheological and fermentation properties of foods. Oliveira *et al.* (2008) have developed yogurt with araticum pulp whereas Bett *et al.* (2017) have produced yogurt with the addition of mangaba pulp. Both studies evaluated the physicochemical properties of the resulting yogurt products. Further, Amaral *et al.* (2020) have evaluated the acceptability of yogurt prepared with mangaba or araticum pulp, sweetened with sucralose.

Yogurt developed using these fruits and with replacement of sucrose by sucralose can present modifications in properties including pH, titratable acidity, texture, and color properties. It is possible that the physicochemical parameters as water activity, luminosity, and textural profile of Greek yogurt are affected more by sucralose compared to sucrose. This study aimed to evaluate the changes in the physicochemical properties and the stability of a Greek yogurt formulated with fruit pulp and with sucralose as the sweetening agent.

## 2. Materials and Methods

### *2.1. Elaboration of Greek yogurt with fruit pulp*

The frozen pulps of fruits were acquired in Goiânia city, packed in polyethylene bags, transported, and stored at -18°C until yogurt preparation at the Instituto Federal de Educação, Ciência e Tecnologia de Mato Grosso-IFMT campus Cuiabá-Bela Vista, in Cuiabá city. Other ingredients such as skimmed milk powder, sugar, and sweeteners were acquired from the local market; the starter culture was obtained from DELVO®YOG FVV 21 1/2U and included *Lactobacillus delbrueckii* sub. *bulgaricus* and *Streptococcus thermophilus*.

The fruit pulps were pasteurized at 75ºC for 30 minutes and then cooled. Next, sucralose was added considering its sweetness equivalent at 50% of sucrose as indicated by Goldsmith & Merkel (2001). Sucralose was chosen due to its sweetening power compared to sucrose.

For preparing Greek yogurt, 2.5 g of skimmed milk powder was added to 100 mL of skimmed milk followed by homogenization and pasteurization at 90ºC for 3 min. The mixture was then chilled to 42°C and 0.2% (v/v) of starter culture was added. The product was stored at 42°C in a biochemical oxygen demand (BOD) incubator until pH 5 and a lactic acid concentration of 0.70% (v/w) were obtained, as described by Amaral *et al.* (2020). Subsequently, to increase the amount of total solids, the yogurt mass was filtered through cotton cloth bags for 24 h at 4°C (EL-Ahwal *et al.,* 2019). Next, sucralose was added to the yogurt as described by Vickers *et al.* (2001) and the magnitude of sweetness was estimated according to Stone & Sidel (2004). The amount of sucralose calculated was 0.0162 g 100 $g^{-1}$ and 0.0182 g 100 $g^{-1}$ for araticum and mangaba Greek yogurt, respectively.

The lightly sweetened Greek yogurt was then mixed and homogenized, and 5% (w/w) of sweetened and pasteurized fruit pulp (araticum or mangaba) was added. The resulting Greek yogurt was packaged in 250 g labelled plastic containers and stored at 4°C in a biochemical oxygen demand (BOD) incubator for further analysis.

Preliminary analyses (data not presented) showed that the yogurt was stabile for 21 days. However, to verify the period for which the product with substitution of sucrose by sucralose remains stable, the storage period was extended to 35 days, according to a study by Bett *et al.* (2017), and the total phenolic content and texture were evaluated after 7 and 28 days.

### *2.2. Physicochemical characterization*

The physicochemical analyses of the araticum and mangaba Greek yogurts were carried out on days 0, 7, 14, 21, 28, and 35 using the AOAC method (AOAC, 2012). The following parameters were evaluated: pH by a digital potentiometer (method no. 943.71); titratable acidity expressed as lactic acid (method 937.05); color using luminosity (L*) and chromaticity (a* and b* parameters) on a CIELab system with a Minolta CM-700D spectrophotometer calibrated to a white standard at three distinct points of the sample; and water activity (WA) using Aqualab 4TE 02 equipment, according to method no.

978.18 and ASTM D6836. All analyses were performed in triplicate.

The contents of moisture, ash, proteins, lipids, glucose-reducing sugars, and lactose-reducing sugars were evaluated after 24 h of storage. Moisture was determined using the oven-drying at 105°C (method no. 950.46); ash was determined using the method of incineration in a muffle furnace at 550°C (method no. 920.153); and the protein content was determined using the Kjeldahl method (method 928.08). The factor 6.38 was used for converting the nitrogen content to the protein content (AOAC, 2012).

The lipid content was evaluated using the Gerber butyrometer method; the reducing sugar contents in the sweetened fruit pulp (araticum and mangaba) and in the Greek yogurt without the pulp were determined using Fehling's solution (IAL, 2008).

*2.3. Total phenolic content*

To determine the total phenolic content an alcoholic extract was prepared with 5 g of the dairy product and ethanol P.A. in a volumetric flask as described by Rufino *et al.* (2010) using the Folin-Ciocalteu reagent.

*2.4. Analysis of texture*

Textural property analyses for the Greek yogurts was carried out using a TA-XT plus texture analyzer - Extralab Brazil, with the following parameters; cross-head speed: 2 mm/s; penetration distance: 5 mm; cylindrical probe 35 mm in diameter (A/BE 35); contact force: 100 g; contact time 5 s; sample volume: 60 ± 10 g; and temperature: 9 ± 2°C under actual storage conditions as described by Amaral *et al.* (2020). The parameters of hardness, compressibility, adhesiveness, and cohesiveness were taken into consideration during the analysis.

*2.5. Statistical analysis*

The results presented are the mean values ± standard deviation of three replicates; changes in pH value were shown in the graphical representation. Data were analyzed using descriptive statistics.

## 3. Results and Discussion

*3.1. Physicochemical characterization*

The fermentation process was continued until pH values of 4.46 to 4.45 and an acidity of 0.79 and 0.84 g 100 $g^{-1}$ were obtained for the araticum and mangaba Greek yogurts, respectively (Table 1).

The pH value is not a mandatory requirement in Brazilian legislation, but is used to verify yogurt quality as it is related to acidity and microbial growth. Bett *et al.* (2019) reported a pH value of 3.73 for mangaba pulp whereas Morais *et al.* (2017) reported a pH value of 4.45 for araticum pulp. In fact, the pH value of the pulp could affect the pH value of yogurt. However, even though different pH values were observed for the fruit pulp was observed, the pH value of the yogurt remained similar. Nevertheless, Bett *et al.* (2017) reported a pH value of 4.93 for yogurt with mangaba pulp and sucrose, which was higher than that obtained in this study.

Furthermore, it is possible that changing sucrose to sucralose does not affect pH and acidity because in studies by Oliveira *et al.* (2008), the pH of the yogurt developed with sucrose and araticum pulp were close to the pH of yogurt with araticum pulp and sucralose. Thus, the acidity and pH of fruits may be relative to the degree of ripeness at the moment of harvest, climatic conditions, and location (Bett *et al.*, 2019). Notably, the acidity and pH parameters of the fruit pulp can affect the yogurt quality, and must be verified when choosing the type of fruit added.

**Table 1:** Physical and chemical characteristics of araticum Greek yogurt and mangaba Greek yogurt

| Parameters of Greek yogurt with pulp of fruit | Araticum flavor | Mangaba flavor | Greek yogurt without pulp* |
|---|---|---|---|
| pH | 4.46 ± 0.01 | 4.45 ± 0.01 | 4.21 |
| Titratable Acidity (g 100 $g^{-1}$) | 0.79 ± 0.02 | 0.84 ± 0.01 | ------ |
| Moisture (%) | 84.04 ± 0.03 | 84.37 ± 0.09 | 82.56 |
| Ash (g 100 $g^{-1}$) | 0.94 ± 0.03 | 0.94 ± 0.01 | 0.91 |
| Protein (g 100 $g^{-1}$) | 10.50 ± 0.66 | 10.10 ± 0.22 | 8.90 |
| Glucose-reducing sugars (g 100 $g^{-1}$) | 21.87 ± 0.77 | 17.58 ± 0.34 | ------ |
| Lactose-reducing sugars (g 100 $g^{-1}$) | 7.52 ± 0.09 | 7.52 ± 0.09 | ------ |

Values are means ± standard deviation; *0% fat Greek yogurt (Labneh) (Kaaki *et al.*, 2012).

In a preference mapping study for Greek yogurt with different fat contents, Kaaki *et al.* (2012) reported a pH of 4.21 for Greek yogurt with 0% fat, whereas the products in the present study presented a higher value. According to Kirdar & Gun (2002), the pH of yogurt can reach values around 3.7 without negatively affecting the product acceptance. The titratable acidity values (as lactic acid) were presented according to the acidity standard established by the current Brazilian legislation (Brasil, 2007). With respect to the soluble solids content in yogurt, Bett *et al.* (2019) found a °Brix value of 14.83 with mangaba pulp whereas Morais *et al.* (2017) obtained a °Brix value of 9.23 with araticum pulp. The presence of simple sugars in the pulp affects the total soluble solids content, as reported by Almeida *et al.* (2016), thus interfering with the physicochemical parameters of yogurt.

Depending on the type of soluble solids in the pulp and the post-harvest storage process, it is possible to obtain different values of WA and reducing sugar content in the same developed products (Carnelossi *et al.*, 2004).



Although the legislation does not stipulate any specific parameters for moisture content, the results obtained in this study were similar between the two fruit flavors and were higher than those reported by Januário *et al.* (2017) who reported a moisture content of 77%. The value of protein found in the products was 10.5 g 100 $g^{-1}$ and 10.1 g 100 $g^{-1}$ for the araticum and mangaba yogurts, respectively. This was partly caused by the use of the desorption process (Table 1), which is characteristic for Greek yogurt and increases the total solids content, reaching up to 12% proteins (Kirdar & Gun, 2002) when compared to plain yogurt, which present a protein content of 3–6% (Mantovani *et al.*, 2012).

The average lipid content was 0.45 g 100 $g^{-1}$ and 0.47 g 100 $g^{-1}$ for the araticum and mangaba flavors, respectively, which is in line with the legislation requirements (Brasil, 2007). Glucose-reducing sugar levels in the araticum and mangaba pulps sweetened with sucralose were 21.87 and 17.58 g 100 $g^{-1}$, respectively.

Simple sugars present in the pulp as well as the lactose present in milk can help the development of starter cultures as they are used by microorganisms as energy sources. Studies by Morais *et al.* (2017) and Melo *et al.* (2013) reported the content of reducing sugars in araticum and mangaba pulps to be 13.87 g 100 $g^{-1}$ and 6.61 g 100 $g^{-1}$, respectively, suggesting that the substitution of sucrose by sucralose in yogurt production did not affect the fermentation process.

### *3.2. Changes in Greek yogurt during storage*

Over 35 days of storage, a decrease in pH from 4.46±0.01 to 4.15±0.02 and 4.45±0.01 to 4.17±0.01 was recorded in the araticum and mangaba flavored Greek yogurts, respectively (Figure 1). According to Alirezalu *et al.* (2019), the ability of microorganisms to produce organic acids interferes with the acidity of yogurt during storage, causing changes in pH over time. Similar values of acidity were found by Maestri *et al.* (2014) in concentrated probiotic fermented milk and by Sert *et al.* (2017) in studies on the characterization of lactic acid bacteria from yogurt.

The fruit pulp-containing Greek yogurts presented WA values ranging between 0.99 and 0.98, respectively. High WA values are expected because this is a common characteristic of yogurts with sucrose, as sucrose added at low concentrations interacts with the water present, which can affect its mobility. However, replacing sucrose with sweeteners having a different chemical composition such as sucralose, could interfere with the mobility of the water present as well as interact with other components such as casein as described by Yaqub *et al.* (2018) who reported the interference of the sweetener with some yogurt variables.

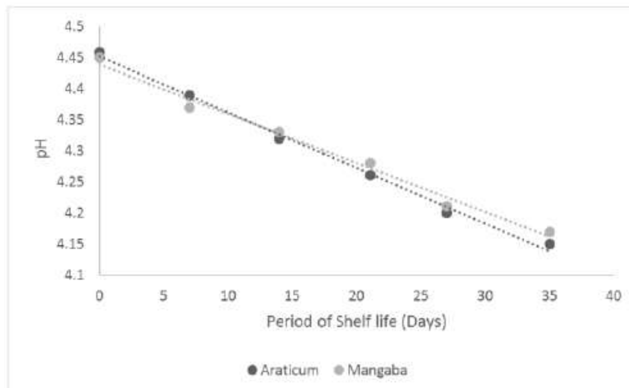


**Figure 1:** pH values during 35 days of shelf life of mangaba Greek yogurt and araticum Greek yogurt.

Storage at 4°C increased the L* from 83.25 ± 0.08 to 88.75 ± 0.02 and from 77.52 ± 0.43 to 85.95 ± 0.88 for the araticum and mangaba Greek yogurts, respectively (Table 2). The araticum Greek yogurt presented higher luminosity (L*), resulting in a higher whiteness when compared to mangaba Greek yogurt. Luminosity changes observed in both yogurt flavors can be related to the level of casein aggregation during the storage period as reported by Sert *et al.* (2017) as well as with the type of fruit used during the manufacturing process.

The values of parameter a* for the araticum Greek yogurt were positive (+a*) and increased

**Table 2:** Color parameters (L*, a*, and b*) of araticum Greek yogurt and mangaba Greek yogurt of shelf life at 4 °C

| Parameters | | Period (days) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 | 7 | 14 | 21 | 28 | 35 |
| L* | Araticum | 83.50±0.08 | 83.55±1.36 | 86.58±0.47 | 87.01±0.21 | 88.49±0.22 | 88.75±0.22 |
| | Mangaba | 77.52±0.43 | 78.00±0.12 | 81.02±0.48 | 83.71±0.62 | 84.45±0.96 | 85.95±0.88 |
| a* | Araticum | 1.68±0.12 | 1.84±0.06 | 1.97±0.08 | 1.98±0.04 | 2.09±0.20 | 2.08±0.24 |
| | Mangaba | -0.62±0.13 | -0.53±0.13 | -0.72±0.07 | -0.94±0.18 | -1.29±0.05 | -1.35±0.08 |
| b* | Araticum | 10.59±0.52 | 10.89±0.28 | 11.22±0.81 | 12.69±0.59 | 12.90±0.49 | 12.71±0.24 |
| | Mangaba | 12.97±0.52 | 13.17±0.29 | 13.03±0.52 | 13.68±0.81 | 14.84±0.15 | 14.53±0.45 |

Values are means ± standard deviation; L*: luminosity; a*: parameter color (+red, -green); b*: parameter color (+yellow, -blue).

with the storage period, trending toward a red color. The values ranged from 1.68 ± 0.12 to 2.08 ± 0.24. This characteristic may be relative to the presence of carotenoid, a natural pigment predominantly responsible for the reddish-yellow color of araticum pulp (Rodriguez-Amaya, 1999). The b* component of the color showed values ranging from 10.52 ± 0.52 to 12.71 ± 0.24.

The values of parameter a* were negative (-a*) for the mangaba Greek yogurt (-0.62 ± 0.13 to -1.35 ± 0.08), indicating a higher green color intensity over the storage period and the b* chromaticity values were positive (12.97 ± 0.52 to 14.53 ± 0.45), tending toward yellow, indicating the probable loss of bright green to olive green color. According to Heaton & Marangoni (1996), this change in color is due to the degradation of chlorophyll in the senescent tissues of the processed plants, in this case, relative to the pulp added to the yogurt.

### *3.3. Total phenolic content*

The total phenolic content of araticum Greek yogurt on storage days 7 and 28 at 4°C were 27.37 ± 3.08 and 15.61 ± 0.57 mg GAE 100 $g^{-1}$, respectively, whereas these values in mangaba Greek yogurt over the same period were 18.54 ± 4.68 and 15.25 ± 0.63 mg GAE 100 $g^{-1}$, respectively. The total phenolic content, short chain acids, and esters in the pulp contribute to flavors and aromas that can lead to a pleasant or unpleasant taste (Melo *et al.*, 2008). In an acceptance study for yogurt produced with mangaba pulp and araticum, Amaral *et al*. (2020) reported that the phenolic compounds and acidity of yogurt were crucial for consumer acceptance.

In general, the phenolic compounds content in mangaba pulp was 935±37 mg GAE 100 $g^{-1}$ and that in araticum pulp was 260.5±0.58 mg GAE 100 $g^{-1}$, as reported by Rufino *et al.* (2010) and Damiani *et al*. (2011), respectively.

**Table 3:** Instrumental texture parameters of araticum Greek yogurt and mangaba Greek yogurt of shelf life at 4 °C

| Parameter | Araticum flavor | Mangaba flavor | Araticum flavor | Mangaba flavor |
|---|---|---|---|---|
| | Day 7 | | Day 28 | |
| **Hardness (kgf)** | 1.24±0.12 | 1.39±0.09 | 1.33±0.16 | 1.42±0.14 |
| **Compressibility (kgf)** | 4.69±0.10 | 5.09±0.13 | 4.86±0.15 | 5.16±0.33 |
| **Adhesiveness (kgf$^{-1}$ mm)** | -0.60±0.08 | -0.98±0.23 | -0.65±0.16 | -1.03±0.15 |
| **Cohesiveness** | -0.42±0.14 | -0.56 ± 0.21 | -0.47 ± 0.10 | -0.61±0.32 |

Values are means ± standard deviation.

Considering that 5% pulp was added to yogurts, the low content of phenolic compounds found in araticum pulp yogurt (13 mg GAE 100 g$^{-1}$) and mangaba pulp yogurt (46.75 mg GAE 100 g$^{-1}$) is justified, and the use of these fruits as flavoring agents for dairy products is recommended.

During storage, the total phenolic content at 7 days was 27.37 ± 3.08 mg GAE 100 g$^{-1}$ for Greek yogurt supplemented with araticum and 18.54 ± 4.68 mg GAE 100 g$^{-1}$ for that with mangaba. At 28 days, a reduction in phenolic compounds content was observed, with 15.61 ± 0.57 mg GAE 100 g$^{-1}$ for Greek araticum yogurt and 15.25 ± 0.63 mg GAE 100 g$^{-1}$ for mangaba yogurt. Even under refrigeration at 4°C, there was a decrease in the content of these compounds, which could be attributed to their potential antioxidant activity (Rodriguez-Amaya, 1999).

*3.4. Textural profile*

Adhesiveness was negative for both products, meaning that the results were similar to those obtained by Mantovani *et al.* (2012), who found an adhesiveness of -0.26 N.s in guava pulp fruit yogurt with 5% milk powder. Probably a higher occupation of the negative area resulted in a greater negative value and, consequently, higher adhesiveness.



The textural parameter analysis showed desirable conditions of shelf life and confirmed that after weeks of storage, the product condition was similar to that of the recently manufactured product (Table 3). However, there were changes in pH value (Figure 1) and color parameters (Table 2).

Studies on the textural parameters of Greek yogurt are quite rare; however, some studies have been carried out to provide additional information such as the work performed by Ramos *et al.* (2009). These authors analyzed the texture of different Greek yogurt formulations, and found values between 1.0 and 1.5 kgf for hardness. Vidigal *et al.* (2012) reported the effect of whey protein concentrate in non-fat dairy desserts, and obtained values ranging between 1.18 and 1.48 N for the hardness of their formulations. This information supports the data obtained in the present work, considering the similar values observed for araticum and mangaba Greek yogurts at 1.33 ± 0.16 kgf, and 1.42 ± 0.14 kgf, respectively after 35 days of storage, compared to the other studies. These values could be associated with a higher protein density of the matrix which enhances its resistance to deformation.

## 4. Conclusion

In conclusion, the results of this study indicate that mangaba and araticum fruit could be used as flavoring agents for Greek yogurt and that sucralose addition does not affect the physicochemical characteristics and shelf-life of the product. There were no undesirable changes in the product characteristics due to the interaction of sucralose with the yogurt constituents. Moreover, the Greek yogurt with fruits pulp remained fit for consumption over 35-day storage, even without the addition of preservatives.

## Conflict of interest

The authors declare that there are not conflicts of interest.

## Ethics

This Study does not involve Human or Animal Testing.

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