https://doi.org/10.71252/2177-34912025720001
ISSN: 2177-3491

Dragon fruit jelly: exploring the potential of peel in post-harvest loss reduction

Deniete Soares Magalhães[1], *Leila Aparecida Salles Pio*[1], *Eduardo Valério de Barros Vilas Boas*[2], *Ana Claudia Costa Baratti*[1*], *Moacir Pasqual*[1], *Ivan Marcos Rangel Junior*[1]

[1] Universidade Federal de Lavras, Departamento de Agricultura, Lavras, MG, Brazil. denietemag@gmail.com, leila.pio@ufla.br, anaclaudia.costa@ufla.br, mpasqual@ufla.br, juniorrangel2@hotmail.com
[2] Universidade Federal de Lavras, Departamento de Ciência dos Alimentos, Lavras, MG, Brazil. evbvboas@ufla.br

*Corresponding author: anaclaudia.costa@ufla.br

Editors:
Wagner Luiz Araújo
Danielle Fabíola Pereira da Silva

Submitted: May 26th, 2024.
Accepted: November 19th, 2024.

ABSTRACT

The aim of this work was to evaluate the potential use of the peel of pitaya fruits for jam production. Four pitaya jelly formulations with different peel proportions used in place of the pulp (0, 20, 40 and 60%) were evaluated. The inclusion of peel in the formulation of red pitaya jelly is viable, and the product quality is maintained, especially at a 20% peel proportion, which is better accepted by tasters than are higher proportions. The 20% substitution of pulp with peel resulted in higher mean consistency and overall impression values than the other formulations. The levels of soluble solids and titratable acidity and the soluble solids/titratable acidity ratio did not significantly differ among the products, with mean values of 64.6%, 1.05%, and 61.67% with 20%, 40% and 60% peel addition, respectively. Substituting pulp with pitaya mesocarp resulted in an increase in jelly pH. The adhesiveness and cohesiveness of the jellies increased as the percentage of peel increased. The microbiological results of this study indicate the absence of microorganisms in the jellies. Thus, the use of peel in jam production can minimize production losses while adding value to the product and reducing waste disposal in the environment.

Keywords: Cactaceae; postharvest; processing; *Selenicereus costaricensis.*

INTRODUCTION

The pitaya, a robust plant of the Cactaceae family, has origins in tropical regions of Mexico and Central and South America[1]. Recognized for its red peel and flesh and dark seeds dispersed within the flesh, the *Selenicereus costaricensis* species stands out as a 'superfruit', captivating the exotic fruit market due to its striking sensory characteristics, particularly its sweet and mild flavor[2]. In addition to its sensory appeal, the pitaya is esteemed for its nutritional profile, which includes vitamins and minerals, having particularly high potassium levels[3].

As highlighted by Jalgaonkar et al.[4] (2022), the pitaya is highly perishable, requiring special care from cultivation through handling, harvesting, storage, processing, transportation and distribution in the market. Given that a significant portion of the production is destined for fresh consumption, establishing an efficient and reliable marketing channel for long-distance transportation poses a significant challenge. In this regard, intensifying postharvest research and development efforts is crucial for strengthening the industry. From a processing perspective, the pitaya has been utilized in the preparation of valuable products such as juices, jams, and preserves.

The red color of the pitaya is attributed to an important pigment called betalain. Furthermore, pitaya peel is a rich source of polyphenols and antioxidants, surpassing even the antioxidant activity found in the fruit pulp[5]. Although the peel represents approximately one-third of the fruit and contains a high concentration of dietary fibers, approximately 69.3%, it is often discarded[6].

The peel is a part of the fruit that is usually neglected by the consumer but has greater functional potential than the pulp[7]. Thus, the use of fruit peels in the production of jams can be highly effective in the generation of new, value-added food products[8].

The transformation of pitaya fruit into products, especially jams, provides new avenues for its utilization and adds value to the fruit. Jams, in particular, are recognized for their sensory acceptance, high added value, and growing demand in the market[9]. In addition to its nutritional value, pitaya peel is of interest to consumers in the food industry and among consumers concerned with a balanced and healthy diet. The economic utilization of fruit residues, coupled with their nutritional and functional benefits, can significantly contribute to the economy and the reduction of environmental impacts.

Jellies are products that can be processed with easily accessible ingredients. However, due to the variability of formulations and interactions between the ingredients used, in addition to technological evaluation, sensory evaluation is necessary to obtain comprehensive information about the potential of the resulting products. However, the use of descriptive sensory methods with consumers provides valid and reliable information on the sensory characteristics of food products[10]. Physical and chemical evaluations of processed foods are also highly important for confirming the physical, nutritional, and sensory qualities of the foods[11].

In this context, in the present study, the potential use of pitaya peel in jam production was evaluated by investigating the effect of substituting different proportions of pulp with peel in the formulation on the physical, physicochemical, microbiological, and sensory characteristics of the final product. The results of this work contribute not only to the development of new food products but also to waste reduction and the valorization of natural resources.

MATERIAL AND METHODS

The pitaya fruits used in this study were acquired from the experimental orchard located in the Department of Agriculture (DAG) of the School of Agricultural Sciences of Lavras (ESAL) of the Federal University of Lavras in the municipality of Lavras, Minas Gerais (21°14"S, 45°00"W, altitude 841 m), which has a climate classified as Cwa, mesothermal or tropical at altitude according to the Köppen classification[12].

Ten kilograms of red pitaya (*S. costaricensis*) was harvested and sent to the postharvest laboratory, where the fruits were washed with neutral detergent, sanitized with 200 ppm sodium hypochlorite (NaClO) for 15 minutes, and rinsed under running water. After the fruits were dried at room temperature, the scales and exocarp were removed with a knife and discarded. Subsequently, the mesocarp and pulp were manually separated and packed in individual plastic bags. The pulp was kept in a refrigerator for 12 hours at 5 °C until the jellies were prepared.

For the formulation of jams, fruit pulp (or pulp + peel), sugar, water, and pectin were utilized as ingredients. The proportions of the ingredients were determined through preliminary laboratory tests. Initially, fruit juices were prepared using a ratio of 60% water to 40% pulp or pulp + peel. The peel was ground in a blender to achieve a homogeneous mass, while the pulp was cut into pieces to maintain seed integrity within the jam. In all formulations, 60% juice and 40% sugar were employed in jam production, with the addition of 1% citrus pectin. Variations among treatments were related to the proportions of pulp and peel in juice preparation for jam formulation (Table 1).

Table 1: Mass (g) of the ingredients for the formulation of pitaya jams with different proportions of peel in place of pulp

Percentage pulp replaced with peel (%)	Ingredients (g)				
	Peel	Pulp	Water	Sugar	Pectin
0	0	420	280	465.5	11.65
20	84	336	280	465.5	11.65
40	168	252	280	465.5	11.65
60	252	168	280	465.5	11.65

Source: Authors (2024).

One-third of the total proportions of sugar and pectin were initially combined and homogenized using a spoon to prevent clump formation. Upon complete dissolution of the pectin, the remaining sugar was added, and the mixture was boiled until reaching 65 °Brix and achieving a gelatinous consistency, with immediate monitoring of the soluble solids content[11]. Subsequently, the jam was removed from heat and transferred to sterilized glass containers that had been previously boiled. After the jars were filled, they were sealed with lids and inverted for five minutes. The packaged jams were then stored overnight in a cool, room-temperature environment until sensory analysis. A subset of the jams was set aside for additional analyses.

The titratable acidity, pH, and soluble solids were analyzed by preparing a homogenate with a ratio of 1 part jam to 2 parts water. The titratable acidity was determined by titrating 10 mL of the homogenate with 0.1 N NaOH using a pH meter, with a pH of 8.2 adopted as the final titration point, and the results are expressed as a percentage of malic acid. The pH of the same homogenate was measured using a pH meter TEC-7 (Tecnal®, Piracicaba, Brazil), while the soluble solids (%) were measured using an ATAGO PR-100 digital refractometer (Tokyo, Japan). The soluble solids/titratable acidity ratio was also calculated with methodologies in accordance with the recommendations of the Association of Official Analytical Chemists[13].

The jam color was analyzed using a CR-400 colorimeter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA) at CIELab/CIELCh color spaces to assess the L*, a*, b*, C*, and h° values, where L* indicates lightness (0 for black, 100 for white), a* indicates green (-80) to red (+100), b* indicates blue (-50) to yellow (+70), C* indicates chroma or color purity, and h is the hue angle. Samples from each formulation were placed in a white container, and readings were obtained from four different locations on the jam sample.

Sensory analyses were conducted at the Laboratory of Sensory Analysis using a structured nine-point hedonic scale ranging from 1 (disliked extremely) to 9 (liked extremely) to evaluate the color, flavor, consistency, and overall impression of the jams by 105 tasters representing both sexes and various age groups. Saltines were provided as a tasting vehicle, with drinking water available to cleanse the palate between samples. The project was approved by the Ethic Committee of the Federal University of Lavras (number 1.522.860).

Texture profile analysis was performed using a stable micro system texture analyzer, model TATX2i, equipped with an HDP/90 platform and a P/6 N needle probe (6 mm diameter, 5 mm s^{-1} speed, 10 mm penetration depth, five second duration) (Godalming, Surrey, United Kingdom). Analyses were conducted in triplicate, and variables such as hardness, adhesiveness, elasticity, cohesiveness, gumminess, chewiness, and resilience were measured.

In the Laboratory of Microbiology, the adoption of the new current legislation RDC 331/2019[14] and RDC 12/2001[15] was carried out, which involved determining the most likely number (MPN g^{-1}) of coliforms per gram of sample at 35 °C and 45 °C, along with the presence or absence of Salmonella and the number of colony forming units (CFU) of molds and yeasts.

The experimental design comprised a completely randomized design (CRD) with four replicates, where each experimental unit consisted of a 100 mL package. Four pitaya jam formulations with different proportions of pulp replaced with mesocarp (0, 20, 40, or 60%) were evaluated. The data were subjected to analysis of variance, and the means were compared using Tukey's test at a 5% probability level with SISVAR software[16].

RESULTS AND DISCUSSION

The fruits were previously characterized regarding their chemical characteristics and presented, on average, a dissolved solids value of 13.16 °Brix, a pH of 4.62, and a titratable acidity of 0.29.

A significant difference in pH was observed among the different jams (Table 2). The jam without mesocarp had the lowest pH recorded (4.79), while the jams containing 40% and 60% mesocarp had the highest pH values, 4.93 and 5.02, respectively. Moreover, jam with 20% mesocarp had an intermediate pH (4.88). Thus, replacing the pulp with pitaya mesocarp resulted in an increase in jelly pH, with higher values observed in the formulation with higher proportions of mesocarp. According to Oliveira et al. [17] (2018), the ideal pH for gel formation is 3.2, with gelation impairment occurring at a pH above 3.4.

In the present study, although higher pH values were found, they did not compromise gel formation. Similarly, Magalhães et al.[18] (2022) reported that the pH increased in samples of white pulp pitaya jelly containing mesocarp material, ranging from 4.64 to 4.93, without compromising gelation. Oliveira et al.[19] (2017) compared the physicochemical variables of jellies made with pitaya mesocarp and those made with pulp from other red fruits, observing a pH of 5.42 for pitaya jellies, without compromising quality. In fresh fruits, Duarte et al.[20] (2017) reported pH values between 4.6 and 5.8 in pitaya (*H. undatus*) cultivated in Lavras, MG. Thus, jellies and other products based on pitaya have relatively high pH values, which may be due to the intrinsic characteristics of the pitaya fruit, which is naturally low in acidity.

The levels of soluble solids, titratable acidity, and the ratio of soluble solids to titratable acidity did not significantly differ among the treatments, with means of 64.6%, 1.05% malic acid, and 61.67%, respectively. The content of soluble solids mainly represents the concentration of sugars and organic acids present in fruits and derived products, such as jellies[21], and the values obtained were within the standards required by Brazilian legislation, which recommends a level of approximately 65 °Brix[22]. In a similar study, Magalhães et al.[18] (2022) did not observe significant differences in the mesocarp content in white pitaya jelly or in the soluble solids content.

Titratable acidity is an indicator of the acidic taste of fruits and is represented by the amount of organic acids in the sample, predominantly malic acid[23]. The ratio of soluble solids to titratable acidity is an important way to evaluate the fruit's taste, with a high ratio suggesting a greater perception of sweetness by the consumer[24]. The average ratio observed in the present study is similar to that reported by Oliveira et al.[19] (2017) in jellies formulated using pitaya mesocarp, indicating a satisfactory taste.

Jellies formulated with and without peel exhibited the characteristic red color of the fruit, with slight variations in shade and appearance due to differences in pulp, peel, and seed concentrations (Figure 1). The variables L*, b*, and h did not significantly differ, with mean values of 16.83, -0.76, and 356.22, respectively, while the variables a* and C* were significantly influenced by peel proportion (Table 2).

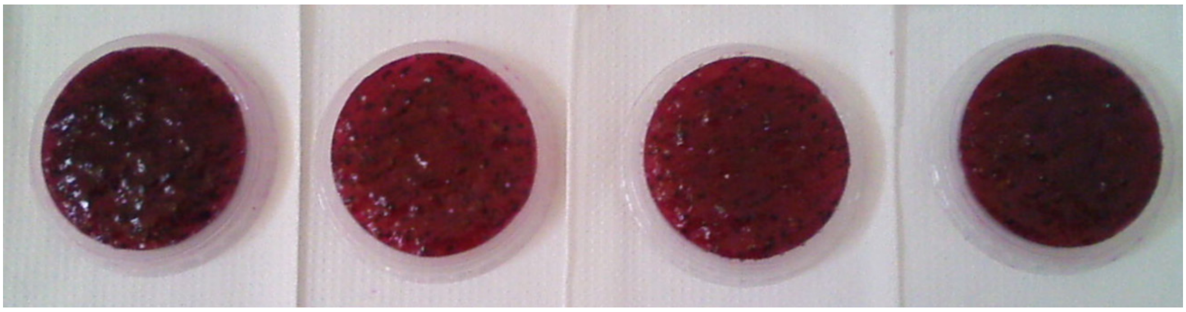
There were no significant differences between jellies in which 20%, 40%, or 60% of the pulp was replaced by peel and the jelly containing no peel. However, the jelly with 20% substitution had higher mean values of a* and C* than did the jelly with 60% substitution, although they did not differ statistically from the 0 and 40% mesocarp concentrations. Positive values of a* are associated with a red color, with higher values indicating a more intense color, while the C* coordinate represents color saturation or purity, with higher values resulting in brighter colors that are more attractive to consumers[25]. Magalhães et al.[18] (2022) observed that the L* coordinate was significantly greater in jelly with 0% to 40% mesocarp than in that with 20% mesocarp, followed by a slight increase in jelly with 60% mesocarp, possibly because the pitaya used in preparation was white pulp and the added mesocarp was red and

Table 2: Mean values and coefficient of variation of pH and color (a* and chroma) for the treatments with different proportions of pulp replaced with peel

Proportion of pulp replaced with peel, %	pH	a*	Chroma
0	4.79c±0.05	19.7ab±3.57	19.76ab±3.55
20	4.88b±0.04	24.52a±4.45	24.56a±4.41
40	4.93a±0.03	18.86ab±3.42	18.94ab±3.40
60	5.02a±0.02	15.86b±2,88	15.91b±2.86
CV (%)	0.80	18.14	17.96
Mean	4.90	19.74	19.79

Source: Authors (2024)

* Means followed by the same letter in the column do not differ at the 5% probability level according to Tukey's test.



Source: Authors (2024)

Figure 1: Appearance of red pitaya jams formulated with different levels of peel used in place of pulp. From left to right: a) 0; b) 20; c) 40; and d) 60% peel.

visibly darker, making the final product darker. The high concentration of mesocarp in the 60% sample caused a decrease in seed concentration, as seeds are only present in the pulp. This result was also observed in the present study.

The characteristic color of pitaya is determined by betalains, a class of water-soluble natural pigments that give attractive colors to groups of fruits and flowers(26). These pigments have high antioxidant activity, giving the jelly greater functional value. Additionally, the mesocarp is a good source of dietary fiber(27). Betalains consist of two subgroups, red–violet betacyanins and yellow–orange betaxanthins(28). According to Abreu et al.(29) (2012), pitaya pulp contains more betalains than does pitaya peel.

Thus, it was expected that replacing pulp with mesocarp would reduce the a* value of the jellies. However, the pulp contains numerous dark seeds that can negatively impact the visualization of the typical red color of pitaya pulp. Since the mesocarp has no seeds, it is believed that substituting 20% of the pulp with mesocarp reduced the impact of the seeds on the red color of the jellies, leading to a higher a* value. As the substitution level increased, the impact of the reduction in seeds was outweighed by the lower intensity of the red color of the peel than that of the pulp and did not result in significant color differences. The highest mean value of C* was also observed in the jelly with 20% substitution, suggesting a product with a more striking red color, as higher C* values result in brighter colors that are more attractive to consumers(25).

According to the results obtained, substituting pulp with pitaya peel did not have a significant impact on the color of the jellies, as determined by sensory analysis. This finding is crucial because it suggests that the change in the reddish hue, identified by instrumental colorimetric analysis, was not noticeable to the tasters. These findings are promising because they indicate that substituting pulp with peel, in any proportion, can be performed without compromising consumer acceptance of the product regarding its color. Additionally, the overall satisfaction average was 8 points, reflecting the tasters' appreciation for the jellies, regardless of the substitutions made.

Regarding flavor, consistency, and overall impression, these attributes were influenced by the proportion of substitution of pitaya pulp by peel (Table 3). Notably, 20% substitution generated the highest averages for consistency and overall impression compared to the other formulations. Jellies with 20% substitution showed averages of 7.56 and 7.73, respectively, indicating moderate to high preference for these jellies by the tasters. Thus, the inclusion of peel contributed to potentially improved consumer approval of the jellies.

Regarding flavor, a significant difference was observed between jellies with 20% and 60% substitution. The former obtained the highest mean (7.46), indicating moderate to high preference, while the latter recorded a mean of 6.87, ranging between "liked a little" and "liked moderately."

The preference of the tasters for the treatment with 20% peel substitution was evident in the sensory analysis. Additional observations from the tasters indicated factors that influenced this preference. Many tasters noted that the seeds provided a pleasant crunchy sensation to the jellies, while formulations containing only pulp had a "sticky" consistency, making it difficult to transfer onto crackers during tasting. For formulations with 40% and 60% substitution, there was a slight reduction in crunchiness due to the decrease in seed quantity. Additionally. some tasters noted a slight decrease in flavor intensity in formulations with 60% substitution, which contained a greater proportion of peel than the other jams. The formulation with 20% substitution was considered the best combination in terms of crunchiness. color intensity, and consistency by some tasters.

Table 3: Mean values, overall mean and coefficient of variation in the acceptability test (flavor, consistency and overall impression) for jams formulated with different percentages of peel

Proportion of pulp replaced with peel (%)	Scores (means)		
	Flavor	Consistency	Overall impression
0	7.04ab±1,42	6.80b±1,49	7.21b±1,22
20	7.46a±1,51	7.56a±1,66	7.73a ±1.31
40	7.19ab±1,45	6.99b±1,54	7.28b ±1.24
60	6.87b±1,39	6.66b±1,46	7.05b ±1.20
CV (%)	20.19	21.98	16.97
Mean	7.14	7.00	7.32

Source: Authors (2024).

*Means followed by the same letter in the column do not differ at the 5% probability level according to Tukey's test.

The findings of Magalhães et al.[18] (2022) in a similar study with white pitaya (*S. undatus*) highlighted that the formulation with 60% peel had the highest overall impression score. However. it is relevant to consider that the authors worked with white pulp pitaya; thus. formulations with relatively high peel contents had a more pleasant red color. which may have influenced the results.

Vanderlei et al.[30] (2020), studying the acceptability of chia jelly and bagasse in the São Francisco River Valley, observed good acceptance, especially for formulations with 70% bagasse, demonstrating the potential for functional products to be well accepted by consumers. Nurhafsah et al.[31] (2023) investigated the composition of jelly candies with added peel and pulp of red pitaya. The results showed a relatively favorable evaluation of all parameters tested by the tasters. with the highest acceptance rate observed for the sample containing 150 g of pitaya peel, 60 g of pitaya pulp, and 290 g of sugar. Fajriyani et al.[32] (2024) investigated the physical and sensory characteristics of sweets and jellies made with natural dyes from beetroot and pitaya peel and concluded that the use of these ingredients significantly impacts the brightness of the colors but does not alter color perception according to the sensory evaluation of the tasters.

Mango and jabuticaba jellies made with the peel and pulp of these fruits were more sensorially accepted than those prepared only with pulp, as reported by Lago-Vanzela et al.[33] (2011) and Dessgimoni-Pinto et al.[34] (2011). The authors attributed this preference to the relatively intense flavor and aroma of the fruits, as well as their similar palatability to that of conventional jelly. Additionally, the authors highlighted that the use of peel adds nutritional value to jellies, in addition to contributing to the reduction in production costs and promoting environmental sustainability. The results of the present study corroborate the observations of these authors.

Although pitaya jelly is still unknown to many consumers, the overall averages of color, flavor, consistency, and overall impression ranged from 7 to 8 on a 9-point hedonic scale. indicating moderate to high acceptance. These results highlight the potential of these jellies for production and commercialization.

Texture profile analysis (TPA) revealed significant differences in hardness, adhesiveness, cohesiveness, gumminess, and resilience among the treatments (Table 4), emphasizing the relevance of textural variables in the perception of food quality and acceptability, reflecting both chemical composition and structure.

Gel formation and its final characteristics are directly influenced by the content of soluble solids, pectin, acidity, and pulp quantity[35]. However, no significant differences were observed in the soluble solids content; the acidity and pectin quantity added to the jellies were standardized, so it is presumed that the observed textural variations are mainly related to the quantity of pulp, peel, and seeds, as well as the heterogeneous distribution of seeds in the samples.

The substitution of pulp with peel resulted in reduced hardness, gumminess, and resilience of the jellies. A reduction in these variables was observed with the substitution of up to 40% of pulp by peel, although jellies with 60% substitution showed greater mean values of these variables than those with 20% and 40% substitution, contrary to the observed trend, but all values were lower than the control values. The adhesiveness and cohesiveness of the jellies increased as the percentage of pulp substituted by peel increased. Adhesiveness increased with increasing substitution proportion; negative adhesiveness values indicate increased stickiness. Cohesiveness was positively affected by substitutions, mainly in the 20% and 40% formulations, but the cohesiveness values were not significantly different.

Table 4: Mean values, overall mean and coefficient of variation for the texture profile (TPA) of the treatments formulated with different percentages of peel

Percentage of pulp replaced with peel (%)	Hardness (g)	Adhesiveness (g.s)	Cohesiveness	Gumminess	Resilience
0	556.19a±29,84	-111.37a±4,23	0.50c±0,023	281.70a±9,77	0.18a±0,011
20	192.16c±17,93	-203.76b±4,05	0.72a±0,027	135.90c ±8,33	0.17a±0,012
40	108.78d±11,62	-221.72c±4,19	0.77a±0,026	83.34d±7,29	0.10c±0,008
60	408.64b±24,67	-299.15d±5,86	0.58b±0,021	237.44 b ±8,91	0.15b±0,013
CV (%)	8.47	1.96	3.74	5.03	6.96
Mean	316.44	-209.00	0.64	184.59	0.15

Source: Authors (2024).

*Means followed by the same letter in the column do not differ at the 5% probability.

The hardness reflects the force required to break the material, while the cohesiveness represents the extent to which a material can be deformed before breaking. Gumminess is determined by the multiplication of these two variables and refers to the energy required to disintegrate a semisolid food to the point where it is ready to be swallowed [36]. Adhesiveness represents the energy required to overcome the attractive forces between the food surface and the surfaces of other materials with which the food is in contact, while resilience is the ability of a body to return to its original size after being compressed, simulating molar action[37].

Fruit pulp is generally soft due to the presence of parenchymal tissue, which has a high water content. On the other hand, the peel is composed of dry dermal tissue, although it may also include parenchymal tissue[38]. However, despite being soft due to the presence of parenchymal tissue. pitaya pulp contains hard seeds, unlike the peel. Thus, the reduction in seed number due to partial substitution of pulp by peel may have led to a decrease in jelly hardness. A similar effect on gumminess was also observed since the reduction in the number of seeds decreases the energy required to turn the jelly into a edible product.

The reduction in the number of seeds also similarly affected the resilience of the jellies, as the reduction in the number of these tiny solid bodies in the jelly, a semisolid food, reduces its ability to recover to its original size after a bite. However, the hardness, gumminess, and resilience of jellies with 60% peel substitution were greater than those of jellies with 20% and 40% peel substitution, probably due to the greater hardness and elasticity of the peel, which affect these textural variables more than the reduction in seed number by 60% peel substitution.

Pitaya peels have approximately twice the dietary fiber content of the pulp[29]. Furthermore, there is more insoluble fiber than soluble fiber in pitaya, and insoluble fibers are present in greater quantities in the peel than in the pulp De Mello[27] et al. (2014). This may cause an increase in peel resistance to heat treatment due to the formation of strong gels that can be used as texture-improving agents in foods. Additionally, the pitaya peel contains more pectin than does the pulp. Iensen et al.[39] (2013), evaluating kiwi jellies, observed that pectin influences the gel texture from 1.5 g 100 g^{-1} onward; below this value, the °Brix did not significantly affect the compression resistance of the jelly. Pectin forms chemical bonds with soluble solids and water in a product, facilitating the formation of a firmer gel with these components. In summary, the effect of pulp seeds on jelly hardness, gumminess, and resilience outweighed the effects of the peel, although this effect was diluted in the 60% peel substitution formulations.

In a study conducted by Lemos et al.[40] (2019), who also used fruit pulps and peels, texture analysis of jabuticaba and acerola jellies revealed that the jelly derived from both jabuticaba pulp and peel had the highest values for texture parameters, except for cohesiveness, due to the mucilage and sweetness of the jabuticaba pulp, which formed a denser and firmer gel. This highlights the importance of the soluble solids concentration in jellies, which can be completed by reducing the water content, increasing the structural rigidity, and increasing the need for the evaporation of a larger amount of water during the cooking process, which affects the gel structure.

A recent study conducted by Magalhães et al.[18] (2022) revealed that the properties of jellies made with the peel and pulp of white pitaya did not significantly vary due to the substitution of pulp by peel, regardless of the level of substitution adopted. These results suggest that peel inclusion can be performed without affecting the textural characteristics of the final product.

In this study, the increase in adhesiveness due to the increase in the substitution proportion may be associated with the lower water content of the peel than of the pulp. Water has a lubricating effect. and its reduction makes foods stickier, resulting in greater adhesiveness. On the other hand, the increase in cohesiveness caused by substitutions may be associated with the reduction in seed number, making the jelly more cohesive. Seeds occupy space in jellies, reducing cohesiveness. Moreover, a reduction in seed number by partial substitution of pulp by peel increases cohesiveness.

Resolution RDC n. 12 from Anvisa[15] establishes microbiological limits for fruit jellies: a maximum of 104 CFU g^{-1} for molds and yeasts, the absence of Salmonella in 25 g of sample, and a maximum of 102 MPN g^{-1} for coliforms at 45 °C. The microbiological results of this study indicate the absence of microorganisms in the jellies, demonstrating that the product was free from contamination and, therefore, in compliance with current legislation. The low pH and high soluble solids content observed in jellies limit microbial growth, especially that of food spoilage and/or pathogenic bacteria, which are sensitive to these variables[41]. Additionally, the results suggest that good manufacturing practices were successfully implemented.

This study provides valuable insights into the potential of pitaya fruit peel in jelly production, revealing promising results worthy of attention. The high sensory acceptability and good quality of pitaya jams, especially those containing 20% peel, reflect the viability of this approach in the food industry.

The use of peels not only proved to be an effective strategy for minimizing postharvest losses but also offered opportunities to add value to the final product. At the same time, by incorporating a byproduct that would otherwise be discarded, peel utilization contributes to reducing food waste and environmental sustainability.

Substituting pulp with pitaya peel in jelly formulations can result in significant savings, mainly from an economic point of view, due to reduced raw material costs, as pitaya peel is often discarded as waste after consumption or use of the pulp. Additionally, it allows for waste utilization, as companies can reduce food waste while increasing the efficiency of their production processes. This not only saves money but can also be positively perceived by consumers and the community at large, as it demonstrates a commitment to sustainability and environmental responsibility. Furthermore, it is a strategy for product diversification and can increase profit margins, leading to better long-term profitability and sustainability of the business.

Therefore, the findings of this study highlight the importance of exploring new sources of ingredients in the food industry, especially those that promote sustainable practices. The use of pitaya fruit peel in jelly production represents not only a smart solution to reduce losses and add value but also a significant contribution to responsible natural resource management and environmental preservation. This approach can serve as an inspiring model for future initiatives in the field of byproduct utilization in the food industry.

CONCLUSION

The inclusion of peel in the formulation of red pitaya jelly is viable, and the product quality is maintained, especially at a 20% peel proportion, which is better accepted by consumers than other substitution levels.

The levels of soluble solids, titratable acidity, and soluble solids/titratable acidity ratio did not significantly differ among the treatments, with mean values of 64.6%, 1.05%, and 61.67%, respectively. However, substituting pulp with pitaya mesocarp resulted in an increase in jelly pH.

The 20% substitution of pulp with peel resulted in higher mean consistency and overall impression values than the other formulations.

The adhesiveness and cohesiveness of the jellies increased as the percentage of pulp substituted by peel increased.

The microbiological results of this study indicate the absence of microorganisms in the jellies, demonstrating that the product was free from contamination and therefore compliant with current legislation.

ACKNOWLEDGEMENTS. FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors acknowledge the National Council for Scientific and Technological Development (CNPq), Coordination for the Improvement of Higher Education Personnel (CAPES), and the Minas Gerais Research Support Foundation (FAPEMIG).

AUTHOR CONTRIBUTIONS

Conceptualization: Leila Aparecida Salles Pio; Eduardo Valério de Barros Vilas Boas; Moacir Pasqual.

Formal analysis: Deniete Soares Magalhães; Ana Claudia Costa Baratti.

Funding acquisition: Eduardo Valério de Barros Vilas Boas; Moacir Pasqual.

Investigation: Deniete Soares Magalhães; Leila Aparecida Salles Pio; Eduardo Valério de Barros Vilas Boas.

Methodology: Eduardo Valério de Barros Vilas Boas; Leila Aparecida Salles Pio.

Project administration: Eduardo Valério de Barros Vilas Boas; Moacir Pasqual; Leila Aparecida Salles Pio.

Resources: Deniete Soares Magalhães; Eduardo Valério de Barros Vilas Boas; Leila Aparecida Salles Pio.

Supervision: Leila Aparecida Salles Pio.

Writing – original draft: Deniete Soares Magalhães; Ana Claudia Costa Baratti; Eduardo Valério de Barros Vilas Boas; Ivan Marcos Rangel Junior.

Writing – review & editing: Ana Claudia Costa Baratti.

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