Efeito da substituição da pectina por casca de banana em características tecnológicas de geleias de abacaxi

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Resumo: A casca de banana representa de 35 a 50% da massa do fruto e é descartada, tornando-se um problema ambiental, embora apresente compostos bioativos. O abacaxi é uma fruta tropical apreciada e bastante consumida após processamento, como geleias, que utilizam a pectina como espessante. Considerando o potencial de uso da casca de banana visando uma economia circular por meio da reciclagem desse resíduo agrícola, foi desenvolvida geleia de abacaxi substituindo a pectina por casca de banana no presente trabalho. Foram produzidas três geleias, a controle, com 50% de polpa de abacaxi, 50% de açúcar, 1% de pectina e 0,65% de ácido cítrico; e formulações com 20% (F1) e 30% (F2) de casca de banana em substituição à pectina. Foram determinados o teor de sólidos solúveis, acidez titulável, pH e cor das geleias, e avaliado seu comportamento reológico. Esses dados foram ajustados aos modelos reológicos: Lei de Potência, Bingham, Herschel-Bulkley e Sisko. Não foram observadas diferenças significativas para os sólidos solúveis totais e a acidez titulável das diferentes formulações. O pH de F2 foi significativamente maior e o controle foi significativamente mais claro que os demais. Comportamento não newtoniano com características tixotrópicas foi verificado para todas as formulações sugerindo afinamento durante o fluxo, o que pode economizar energia para esta operação. A casca de banana apresentou potencial para substituir a pectina para produzir geleia de abacaxi, apontando para a viabilidade de reutilização deste subproduto e minimização do desperdício agrícola.

Palavras chave: *Musa* sp.; Resíduo agroindustrial; Reologia; Modelagem matemática.

Effect of replacing pectin for banana peel on technological characteristics of pineapple jams

Abstract: Banana peel represents 35-50% of the fruit mass and is dropped out, becoming an environmental problem, although it presents bioactive compounds. Pineapple is an appreciated tropical fruit that is quite consumed after processing, such as jams, which use pectin as a thickener. Considering the potential of using banana peels aiming at a circular economy through recycling this agricultural waste, pineapple jam was developed replacing pectin with banana peel in the present work. Three jams were produced, the control, with 50% of pineapple pulp, 50% of sugar, 1% of pectin, and 0.65% of citric acid; and formulations with 20% (F1) and 30% (F2) banana peel to replace the pectin. Soluble solids content, titratable acidity, pH, and color of the jams were determined, and their rheological behavior was evaluated. These data were adjusted to the rheological models: Power Law, Bingham, Herschel-Bulkley, and Sisko. No significant differences were observed for the total soluble solids and the titratable acidity of the different formulations. The pH of F2 was significantly higher and the control was significantly clearer than the others. Non-Newtonian behavior with thixotropic characteristics was verified for all the formulations suggesting thinning during flow, which can save energy for this operation. Banana peel presented the potential to replace pectin to produce pineapple jelly, pointing to the feasibility of reusing this by-product and minimizing agricultural waste.

Keywords: *Musa* sp., Agroindustrial waste; Rheology; Mathematical modelling.

Introduction

Banana production was near 140 million tons in 2023, with a harvested area of almost 6 million hectares, and India was the world's largest producer (FAOSTAT, 2025[a,b]). According to Zaini *et al.* (2022), banana plantations and processing generate tons of residues each harvest season, which are dumped in the environment. Considering that banana peels represent 35-50% of the total mass of the fruit (Zaini *et al.*, 2022), about 50 million tons of this waste is generated annually in the world. Due to the amount of residues, agro-industrial activities and industrial manufacturing significantly impact the environment (Vukušić *et al*., 2023).

To contribute to sustainability in the frame of a circular economy, lots of attention has been given to evaluating the chemical composition and the biologically active compounds of banana peels, and it has been found that it is rich in polyunsaturated fatty acids, it is a good source of amino acids, contains fibers, minerals, and some vitamins, such as vitamin C, and presents antioxidant, anticarcinogenic and antimicrobial activity (Zaini *et al.*, 2022; Hikal *et al.*, 2022; Toupal and Coşansu, 2023). Besides, Karne *et al.* (in press) studied extracting biodegradable material from banana peels aiming to substitute plastics in packaging manufacture, and Chinnathambi *et al.* (2024) extracting pectin from the flour of banana peels of different varieties to be used as a thickener or a stabilizer.

Pineapple is a tropical fruit very appreciated, which can be consumed in various ways such as dehydrated, canned, or converted into juices, jams, jellies, and so on (Abraham; Jayasree and Abdullah, 2023). Almost 30 million tons of pineapple were produced in 2023 (Faostat, 2025[a]) and about a third of the production is industrially processed yearly (Abraham; Jayasree and Abdullah, 2023). The fruit is perishable and its post-harvest losses are great, however, due to its high nutritive value and aroma, preserved after processing, it can be used to produce many added-value products, such as jam, beverages, and powder. Approximately 80% of the pineapples sold is processed, mostly as canned pineapple slices, tetra-packed beverages, squash, dehydrated slices, and jam (Abraham; Jayasree and Abdullah, 2023).

According to Abraham, Jayasree and Abdullah (2023), jam is a thick gel made from fruit pulp, sugar, and pectin. The authors attested that:

> "Pineapple Jam is prepared by cooking the fruit pulp and sugar with continuous stirring. Pectin powder is added to the mixture after a few minutes, which imparts the desired texture to the jam. After reaching the desired consistency the cooking operation is stopped and the jam is allowed to cool (Abraham; Jayasree and Abdullah, 2023, p. 3)."

In intermediate moisture food products like jam, jellies, and marmalades, pectin, the complex polysaccharide usually extracted from citrus peels, acts as a gelling, glazing, stabilizing, and thickening agent. Pectin from banana peel presents a potential for industry application due to the possible increase in pectin demand over the next years (Chinnathambi *et al.*, 2024).

Basu and Shivhrare (2010) pointed out that changes in jam formulations can be related to texture changes because the gel structure of jams usually changes when variating ingredients or their concentrations. The gel structure is perceived by consumers through the mouthfeel, which is influenced by texture and correlated with rheological properties.

According to Ciolin, Lenhard and Garcia (2023), rheological properties can be determined by measuring stress and strain as a function of time, defining the behaviour of the fluid, which can be represented by a mathematical model, relating how the shear stress varies with the strain rate. The data on rheological processes play crucial roles in understanding the fundamental and technical aspects of fluid transportation operations in industries, which can affect sensory aspects of many food products (Atik; Oztürk and Akin, 2024), especially those with thick characteristics.

Considering the potential of using banana peel as raw material for developing new products, this research aimed to evaluate the effect of replacing pectin with banana peel on some technological characteristics of pineapple jams.

Material and Methods

Materials

The bananas and pineapples were purchased at a local market and were selected based on their visual maturity: they were ripe but firm. In this sense the banana peels were yellow but without black spots and the pineapple peels were mostly orange without any injuries.

The refined sugar cane was purchased at the local market, the monohydrate citric acid food standard (192.13 g/mol) was purchased from Anidrol (Diadema, SP, Brazil), and the pectin from citric peels (CAS 9000-69-5) was purchased from Dinâmica (Indaiatuba, SP, Brazil).

Preparation of the jams

The fruits were washed and sanitized for 5 min in a 200 mg L^{-1} sodium hypochlorite solution. Then, they were rinsed in distilled water and dried with absorbent paper. After the sanitization, the fruits were peeled, and the pineapples were weighed in portions of 800 g. Based on preliminary tests and practical technologies that could be applied on a small and homemade scale to add value to banana waste, the banana peels were cooked in boiling water for 20 minutes in a proportion of 10 L of water for each kg of peel. After that, they were drained, and the appropriate amount was weighed for each formulation, mixed with the pineapple pulp portion, and crushed. The proportions of banana peel to be used were defined based on preliminary tests where the color, flavour, aroma, and spread ability should be as similar as possible to the characteristics of the control jam, which was produced with 1% pectin (related to the sugar mass), without banana peel. The proportions of each ingredient used in the jams production are presented in Table 1.

Table 1 – Formulations of the jams produced.

	Pectin	Banana peel	Pineapple pulp	Sugar	Citric acid
F1	-	20%	50%	50%	0.65%
F2	-	30%	50%	50%	0.65%
Control	1%	-	50%	50%	0.65%

The amounts of pectin, banana peel and citric acid were weighted concerning the sugar mass, i.e., for 0.80 kg of sugar, 0.80 kg of pineapple pulp, 0.0052 kg of citric acid, 0.008 kg of pectin (control), and 0.160 or 0.240 kg of banana peel (F1 and F2, respectively) were used to produce the jams.
Source: Own authorship (2024).

As described by Abraham, Jayasree and Abdullah (2023), the crushed pineapple pulp and the sugar were cooked with continuous stirring until boiling, when the citric acid was added. After the sugar was completely dissolved, the pectin was added to the control formulation. When preparing the replaced-pectin formulations, the crushed pulp presented adequate amounts of pineapple pulp and banana peel, as described in Table 1.

Each formulation was produced in triplicate, and the cooking process was carried out for 30 min to standardize the procedure and avoid overheating which could result in high values of total soluble solids content (TSS). It is important to highlight that high TSS values enable the modelling of the rheological behaviour of the jams due to the equipment limitations. Therefore, it was intended to control the TSS content of the jams.

After the cooking process, the jams were placed in sterilized glass jars, which were cooled to avoid the overheating of the samples.

Physical-chemical evaluations of the jams

The physical-chemical evaluations of the jams were carried out in triplicate for each formulation, as follows: pH, titratable acidity, total soluble solids content, and instrumental color measurement, following recognized proceedings.

The pH was determined using a digital pH meter (PHS 3, Bel Engineering, Italy). The titratable acidity was determined by homogenizing a 5 g sample in 50 mL of water using phenolphthalein as an indicator and 0.1 M sodium hydroxide solution as titrant. Total soluble solids (ºBrix) were determined with a calibrated refractometer (HI96803, Hanna Instruments, Italy). The color measurement was performed on a Minolta colorimeter (Chroma meter CR-300, Konica Minolta, Japan) using the L*, a*, b* system with D65 illuminant and 10º of reading angle. The color parameters evaluated were luminosity L* (100 for white and 0 for black); and chromaticity coordinates of the CIE/LAB system: a*, (-) for green and (+) for red, and b*, (-) for blue and (+) for yellow.

Rheological evaluation of the jams

Rheological evaluation was performed in triplicate for each formulation using a Brookfield (Middleboro, USA) rotational viscometer with concentric cylinders, model LVDV – III ULTRA, with the spindle SCA – 25 for determining the variations on shear stress with strain rate. The steady-state measurements were performed at a controlled temperature of 25 °C (Bio Termo 10 thermostatic bath, 7Lab, Brazil), and the strain rate ranged from 0 to 33 s^{-1}. Both ascendent (increasing the strain rate) and descendent (reducing the strain rate) ramps were evaluated to assess (or not) the thixotropic behavior of the samples with a pass of 30 s between them. For each strain rate, a 2-minute step for both ascending and descending ramps was performed, and four shear stress values were collected. Therefore, for each curve, third eight shear stress points were obtained, whose averages were calculated for each strain rate value.

The steady-state rheological data of shear stress versus strain rate were adjusted to the models represented by Eqs. 1-5 presented in Table 2.

Table 2 – Models to describe the rheological behavior of the jams.

Mathematical model		Eq.
Newton	$\tau = \mu \cdot \dot{\gamma}$	(1)
Power Law	$\tau = K \cdot \dot{\gamma}^{n}$	(2)
Herschel-Bulkley	$\tau = \tau_0 + K \cdot \dot{\gamma}^{n}$	(3)
Sisko	$\eta_a = \eta_a + \eta_\infty + K \cdot \dot{\gamma}^{n_s - 1}$	(4)
Bingham	$\tau = \tau_0 + \mu_B \cdot \dot{\gamma}$	(5)

In which: τ is the shear stress, Pa; τ_0 is the yield stress, Pa; $\dot{\gamma}$ is the shear rate, s^{-1}; μ is the viscosity, Pa·s; μ_B is the plastic viscosity, Pa·s. η_a is the aparent viscosity, Pa·s; η_∞ is the viscosity at infinite shear rate, Pa·s; K is the flow consistency index, Pa·s^n; n, n_s are the flow behavior index, dimensionless.
Source: Own authorship (2024).

Statistical evaluations

A one-way analysis of variance for all the physical-chemical data was carried out, and the significant differences ($p < 0.05$) among the mean values were determined by Tukey's test.

The rheological parameters were obtained by the method proposed by Levenberg-Marquadt (Marquadt, 1963), through non-linear regression using the least squares method to adjust the experimental data to the models presented in Table 2, using a convergence criterion of $1 \cdot 10^{-6}$.

To verify the adjustment of the models presented in Table 2 to the experimental data the values of the coefficient of determination (R^2), the mean squared error (*RMSE*, Eq. 6), the mean relative error (*P*, Eq. 7), and the bias factor (B_f, Eq. 8) were evaluated considering that the first two parameters denote good fit when their values are close to 1 and low, respectively (RUDY *et al.*, 2015), and that *P* should be lower than 10% (Krokida and Marinos-Kouris, 2033).

$$RMSE = \left[\frac{\sum_{n=1}^{n}(x_{exp} - x_{calc})}{n}\right]^{1/2} \quad (6)$$

$$P = \frac{100}{n}\sum_{i=1}^{n}\frac{|x_{exp} - x_{calc}|}{x_{calc}} \quad (7)$$

$$B_f = 10^{\left|\frac{\sum_{n=1}^{n} log\frac{x_{calc}}{x_{exp}}}{n}\right|} \quad (8)$$

In which: x_{exp} is the experimental value, x_{calc} is the value predicted by the model, and n is the number of experimental observations.

Results and Discussions

Physical-chemical evaluations of the jams

The physical-chemical characteristics of the jams are presented in Table 3.

Table 3 – Physical-chemical characteristics of the pineapple jams.

	TSS (°Brix)	**Titratable acidity (g citric acid/100 g)**	**pH**	**L***	**a***	**b***
F1	59.2ᵃ ± 0.2	0.57ᵃ ± 0.1	3.27ᵃ,ᵇ ± 0.05	28.4ᵇ ± 0.27	0.23ᵃ ± 0.83	7.97ᵇ ± 0.72
F2	59.67ᵃ ± 1.7	0.63ᵃ ± 0.2	3.44ᵃ ± 0.1	25.77ᶜ ± 0.14	-1.27ᵇ ± 0.41	9.86ᵃ ± 0.36
Control	62.03ᵃ ± 1.5	0.58ᵃ ± 0.1	3.01ᵇ ± 0.05	36.44ᵃ ± 0.29	-3.23ᶜ ± 0.41	6.78ᶜ ± 0.4

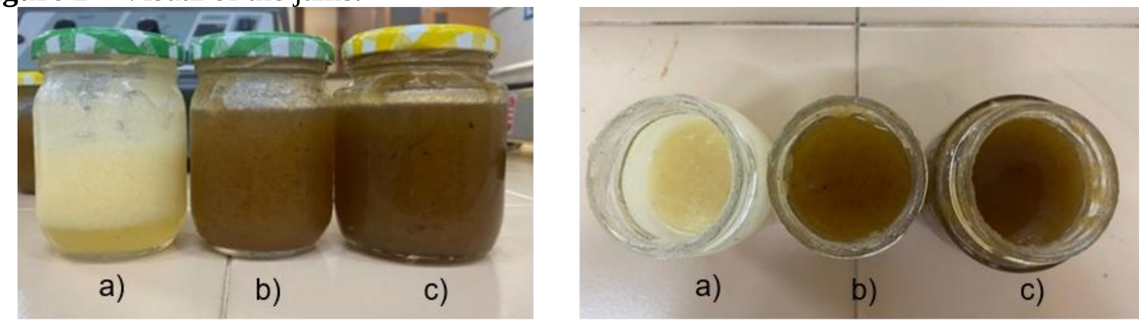
Results presented as mean ± standard error (n = 3). Mean values in the same column with different letters are significantly different ($p < 0.05$).
Source: Own authorship (2024).

As shown in Table 3, the jams manufactured with banana peels presented significantly lower values of TSS than the control sample produced with pectin. Using banana peel instead of pectin did not affect the titratable acidity of the pineapple jams within the ratios evaluated, but influenced their pH. The pH of the jams with banana peel was significantly higher than that of the control sample. This was unexpected for two reasons: one related to the composition of the peels and another to the composition of the jams. Banana peels contain organic acids and phenolic compounds (Zaini *et al.*, 2022) that could reduce the pH of the jams, which didn't occur, possibly due to the small amounts used in the formulations. On the other hand, as the titratable acidity wasn't affected by replacing pectin for banana peels within the proportions evaluated, the same effect was expected regarding the jams' pH, which also didn't occur. The researchers believe that this result is related to the fact that the peels were crushed to produce the jams, and possibly the organic acids were not fully transferred/solubilized in the jam.

Molla *et al.* (2022) produced guava-pineapple jellies with honey and lemon juice and found an acidity of 1.01 g of citric acid·100 g^{-1} of sample, higher than in the present research due to the lemon juice addition. The authors also verified that the pH of the jellies was 3.38, similar to the findings of the present work. The authors also evaluated the sensory aspects of the jams and the results showed that the formulations with honey and lemon juice were the panelists' favorites (Molla *et al.*, 2022).

Regarding the color, the control, produced with pectin, was the most luminous, the greenest, and the least yellow among the jams that were produced in the present research. Adding banana peels decreased the luminosity and increased the yellowish and redness of the jams. Therefore, while the color of the control jam was similar to the commercial pineapple jam, the ones with banana peel presented a dark brown aspect, as can be seen in Fig. 1, which presents the visual of the samples. This dark brown aspect of the peel-added jams was probably a result of enzymatic and nonenzymatic browning. The enzymatic browning of the peels could not be discharged since Ôba *et al.* (1992) found two isozymes of polyphenol oxidase (PPO) from banana bud and verified that both presented high heat stability, with up to 95% of their initial activities retained after 1-h incubation at 70 °C. Considering that, it is possible that the heating of the peels in boiling water for 20 min wasn't enough to inactivate the PPO and, as a result, both enzymatic and non-enzymatic browning were responsible for the dark color of the jams produced with the by-product.

Figure 1 – Visual of the jams.



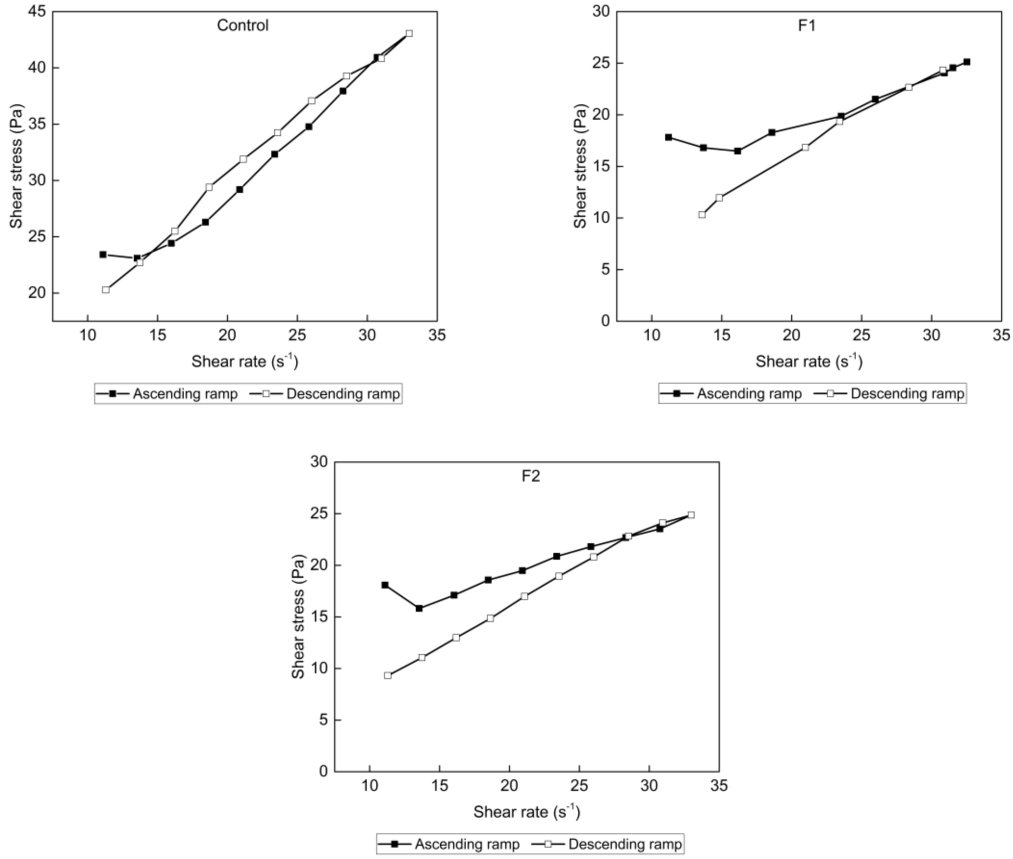
a) Control (with 1% of pectin), b) F1 (with 20% of banana peel replacing the pectin), c) F2 (with 30% of banana peel replacing pectin).
Source: Own authorship (2024).

Therefore, considering the physical-chemical data, it was verified that banana peel is a potential gelling agent to replace conventional pectin in the manufacturing of pineapple jams, but it is necessary to adjust and optimize the processing parameters to obtain a product with characteristics closer to those of the commercialized ones.

Rheological evaluation of the jams

The changes in shear stress of the jams as increasing (ascending ramps) and decreasing (descending ramps) the strain rate can be seen in Fig. 2. It is important to highlight that no differences were verified among the results of the triplicates of the ascending (strain rate ranging from 0 to 33 s^{-1}) and the descending (strain rate ranging from 33 to 0 s^{-1}) ramps for each formulation. Therefore, the average data for each formulation is presented in Fig. 2.

Figure 2 – Variations in the shear stress of the jams as a function of shear rate.



Source: Own authorship (2024).

As shown in Fig. 2, regardless of the use of pectin or banana peel as a gelling agent, all the samples showed non-Newtonian behavior, with no straight linear relationship of the shear stress with the strain rate (Steffe, 1996) for both ascending and descending ramps.

It is also seen in Fig. 2 that the stress was higher when increasing the strain rate (ascending ramps) than it was on decreasing (descending ramps). According to Larson and Wei (2019), this behavior is consistent with thixotropy, “in which shear breaks down structures, leading to a reduced viscosity that does not have time to recover before the second half of the cycle occurs”. This is an interesting behavior considering the transport of the jams in pipes because their thinning during shear could result in energy savings. In terms of sensory properties, the influence of thixotropy can be evaluated as a firmer texture becoming fluid as shear undergoes (shaken/mixed). Thixotropy was also verified for mango jam (Basu and Shivhare, 2010) and pineapple jam (Basu, Shivhare and Raghavan, 2007).

The data of both ramps of strain rate versus shear stress were adjusted for the rheological models presented in Table 2. Based on the statistical parameters used to evaluate the fit, the Bingham model best represented the data since the values of R^2 were close to 1, of *RMSE* were lower than 3.81, of P were lower than 10%, and of B_f were close to zero, as presented in Table 4. The rheological parameters of the model are also presented in Table 4.

Table 4 – Statistical parameters to evaluate the fit of the rheological data to the Bingham model and parameters of the model for the ascending and descending ramps of the jams.

		Statistical parameters				Model parameters	
		R^2	SE	P (%)	B_f	μ_B (Pa·s)	τ_0 (Pa)
F1	AR	0.89	3.91	5.04	0.004	0.424 ± 0.052	10.658 ± 1.207
	DR	0.98	4.38	1.97	0.038	0.726 ± 0.022	1.859 ± 0.463
F2	AR	0.92	1.20	3.17	-0.003	0.381 ± 0.041	11.837 ± 0.947
	DR	0.99	1.88	1.36	0.014	0.747 ± 0.018	1.000 ± 0.422
Control	AR	0.97	1.43	3.42	-0.006	0.986 ± 0.061	9.735 ± 1.406
	DR	0.99	1.09	1.90	0.007	1.061 ± 0.032	8.742 ± 0.744

AR means ascending ramp and DR, descending ramp. Results presented as mean ± standard error (n = 3).
Source: Own authorship (2024).

As pointed out by Steffe (1996), in the Bigham model the yield stress (τ_0) represents the minimum stress required to achieve flow. Below the yield stress value, the fluid behaves as a solid which means that it stores energy at low strains. Above the yield stress value, the fluid flows as Newtonian, i.e., a direct relation between shear stress and strain rate can be observed (Steffe, 1996), as in Fig. 2. The importance of the yield stress is related to the spreadability (Steffe, 1996) of the jams. In the present research, the yield stress of the control jam was slightly lower than the ones with banana peels, indicating that consumers probably wouldn't feel the difference in the spreadability of the samples.

In addition, the Bingham viscosity pattern between the ascendant and descendant curves did not change significantly with an increase in banana peels concentration from 20% to 30%, with differences of 0.302 Pa·s for F1 and 0.366 Pa·s for F2, respectively. Meanwhile, the yield stress for the ascending curves was higher than for the descending ones, because jams had already been subjected to stress, being, therefore, more fluid and easier to flow. These findings are in agreement with other researches that highlight that the hysteresis area is related to structural damage or destruction during shearing, which is greater the higher the viscosity of the thixotropic fluid (Xie *et al.*, 2022; Gao *et al.*, 2011). Additionally, no significant difference in viscosity or yield stress was observed for the control samples.

Within the replacement proportions evaluated in the present research, these results suggested that replacing the traditional pectin-gelling agent with banana peels resulted in small changes in the structural/rheological properties of pineapple jams compared to the control.

Therefore, the stability during the jams' production and the energy consumption during processing would probably not change. Additionally, the sensory perception of the consumers probably wouldn't be affected as well.

Conclusions

This research highlighted the potential of using banana peels as a gelling agent for producing pineapple jam, leading to innovation, the reusability of this by-product, and, considering the literature, enriched food products. However, improvements to the processing parameters, such as peel concentration and using the proper techniques to avoid enzymatic and non-enzymatic browning, are necessary to obtain pineapple jams with characteristics closer to those of the commercialized ones.

Regarding the rheology characteristics of the jams, they presented non-Newtonian and thixotropic behavior. The changes in rheological properties from replacing pectin with banana peels indicated small sensory changes, which probably wouldn't affect the acceptability of the new formulations. Besides, the thinning of the jams during flow can result in energy savings for this operation, which is interesting to the food processing industry.

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Conflict of interest

The authors report that there are no competing interests to declare.

All authors have participated in (a) conception and design or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

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Authors' contribution

In detail, the author's contributions were as follows:

MLBC Kossar was responsible for the Conception and design of the work, Data collection, Data analysis and interpretation, and Performing the analysis; IHMR Ciolin participated in the Data analysis and interpretation, Drafting the article, Critical revision, and Final approval of the version to be published; NC Steinmacher and DC Lenhard participated in the Data analysis and interpretation, Critical revision, and Final approval of the version to be published; GC Moreira was responsible for the Conception and design of the work, Methodology, Data analysis and interpretation, and Final approval of the version to be published; C.C. Garcia was responsible for the Conception and design of the work, Methodology, Data analysis and interpretation, Drafting the article, Critical revision, and Final approval of the version to be published.

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