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Effect of the addition of psyllium *(plantago ovata* forsk) on the physicochemical characteristics of frozen banana pulp during storage

Efeito da adição de psyllium (plantago ovata forsk) nas características físico-químicas da polpa de banana congelada durante o armazenamento

Efecto de la adición de psyllium (Plantago ovata Forsk) sobre las características fisicoquímicas de la pulpa de banano congelada durante el almacenamiento

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Abstract
Psyllium is a soluble fiber that has aroused the interest of several researchers for presenting proven functional benefits such as reducing LDL cholesterol, controlling blood glucose, delaying gastric emptying time among others. This study aimed to elaborate a banana pulp added psyllium and verify the effect on the physicochemical parameters (pH, total titratable acidity, color and rheology) during 90 days of storage under different temperatures (- 8 °C and – 18 °C). The results showed that the addition of 3% psyllium altered some parameters: the pH did not present a significant difference at time 0, but at times 30 and 60 it showed a difference and at the end of storage it did not show any difference, the ATT did not change at time 0 , but from time 30 it showed a significant decrease until the end of the storage period, the psyllium having a darker color than the banana reduced the luminosity (L *), it was verified that the addition of psyllium increased the apparent viscosity of the pulp. Psyllium has the potential to be used in banana pulp, since the changes in pH and TTA did not affect the quality of the product and meet the recommended by the current quality and identity standard for banana pulp, being a viable product with functional properties that can receive health claims.
Keywords: Functional food; Health; Fruit; Health claim; Hydrocolloid.

Resumo
O *psyllium* é uma fibra solúvel que tem despertado o interesse de vários pesquisadores por apresentar benefícios funcionais comprovados como a redução do colesterol LDL, o controle da glicemia, retardo do tempo de esvaziamento gástrico entre outros. Este estudo objetivou elaborar uma polpa de banana adicionada de *psyllium* e verificar o efeito nos parâmetros físico-químicos (pH, acidez titulável total, cor e reologia) durante 90 dias de estocagem sob diferentes temperaturas (- 8 °C e – 18 °C). Os resultados mostraram que a adição de 3% de *psyllium* alterou alguns parâmetros: o pH não apresentou diferença significativa no tempo 0, porém nos tempos 30 e 60 apresentou diferença e ao final do armazenamento não apresentou diferença, a ATT não apresentou alteração no tempo 0, mas a partir do tempo 30 apresentou um decréscimo significativo até o final do período do armazenamento, o *psyllium* por possuir uma coloração mais escura que a banana reduziu a luminosidade (L*), verificou-se que a adição de *psyllium* aumentou a viscosidade aparente da polpa. O *psyllium* tem potencial para ser utilizado em polpa de

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banana, visto que as alterações no pH e ATT não afetaram a qualidade do produto e atendem ao preconizado pelo padrão de qualidade e identidade vigente para polpa de banana, sendo um produto viável com propriedades funcionais que pode receber alegação de saúde.
Palavras-chave: Alimento funcional; Saúde; Fruta; Alegação de saúde; Hidrocoloide.

Resumen

El psyllium es una fibra soluble que ha atraído el interés de varios investigadores porque tiene comprobados beneficios funcionales como reducir el colesterol LDL, controlar la glucosa en sangre, retrasar el tiempo de vaciado gástrico, entre otros. Este estudio tuvo como objetivo elaborar una pulpa de banano adicionada con psyllium y verificar el efecto sobre los parámetros fisicoquímicos (pH, acidez total titulable, color y reología) durante 90 días de almacenamiento a diferentes temperaturas (-8 ° C y -18 ° C). Los resultados mostraron que la adición de psyllium al 3% cambió algunos parámetros: el pH no mostró una diferencia significativa en el tiempo 0, pero en los tiempos 30 y 60 no difirió y al final del almacenamiento no hubo diferencia, ATT no cambio en el tiempo 0, pero desde el tiempo 30 mostró una disminución significativa hasta el final del período de almacenamiento, el psyllium al tener un color más oscuro que el plátano redujo la luminosidad (L *), se encontró que la adición de psyllium aumentó la viscosidad aparente de la pulpa. El psyllium tiene el potencial de ser utilizado en la pulpa de banano, ya que los cambios de pH y ATT no afectaron la calidad del producto y cumplieron con los requisitos del estándar actual de calidad e identidad para la pulpa de banano, siendo un producto viable con propiedades funcionales que pueden recibir una declaración de propiedades saludables.
Palabras clave: Alimento functional; Salud; fruta; Declaración de propiedades saludables; Hidrocoloide.

1. Introduction

Due to health concerns, consumers are making better food choices (Ali & Ali, 2020). Functional foods are being included in diets more often, these products can receive health claim statement on the label and this is a competitive differential in the market (Domínguez Díaz, Fernández-Ruiz, & Cámara, 2020).

Many countries aim in their public policy to improve the dietary diet of the population. The awareness about the health benefits in the consumption of plant foods has caused the increase in demand for these products and with this has driven the food industry to seek healthier food alternatives and to develop more products of plant origin (Huang, Bai, & Gong, 2020; J. Liu et al., 2020).

Psyllium is a plant with a high content of soluble fiber (found in the bark of the seeds of *Plantago ovata)* that has several proven functional benefits such as reducing LDL cholesterol, controlling blood glucose, laxative, slows the time of gastric emptying and have been studied by many researchers. It has been successfully added in food products, mainly as a source of hydrocolloid in gluten-free formulations, but the addition of psyllium in plant products is scarce (Belorio, Marcondes, & Gómez, 2020; Franco et al., 2020; Fratelli, Muniz, Santos, & Capriles, 2018; Peressini, Cavarape, Brennan, Gao, & Brennan, 2020; Santos, Aguiar, Centeno, Rosell, & Capriles, 2020). According to Fradinho, Soares, Niccolai, Sousa, & Raymundo (2020) psyllium when added in food increases the fiber content and reduces the glycemic index.

According to Farahnaky, Askari, Majzoobi, & Mesbahi (2010) due to the beneficial effects of psyllium, fortified foods may have a higher acceptance by the consumer.

In Brazil, the food product that has at least 3 g of psyllium per serving can put on the label the health claim (Brazil, 1999), so far there is no offer to consumers of many products in this condition. Adding fiber in food products is not a simple task, as it can change the rheological properties, color, texture, taste. Some researchers have studied the addition of fiber in products with fruits such as jellies (Figueroa & Genovese, 2019) and nectar (Huang et al., 2020).

Another market that presents growth next to the market of functional products is the one of frozen fruit pulp, given the easy preparation, nutritional benefits, and sensory acceptance, in addition to reducing fruit losses due to their perishability (Orqueda et al., 2021). Brazil is the third largest fruit producer, having frozen pulp processing as one of the main industrial fruit products (Alamar, Caramês, Poppi, & Pallone, 2016). Many countries showed an increase in fruit pulp production, such as the United States with an increase in the rate of 1.3% in 2015 (IBISWord, 2015).

According to Storey & Anderson (2018) the daily consumption of fruits in the United States is below the recommended by the Dietary Guidelines for Americans 2015 – 2020 and frozen fruits can assist for greater consumption of this food. The study showed that consumers of frozen fruits and vegetables ingested a higher concentration of nutrients such as vitamin k, D, calcium and fiber. The authors stated that the supply of frozen fruits and vegetables has advantages such as convenience and reduction in waste, being an important criterion especially for low-income groups.

Mason-D'Croz et al. (2019) conducted a survey on the future supply of fruits and vegetables and recommended consumption levels in more than 150 countries by 2050 and found that fruit production will be insufficient to meet the nutritional recommendations of the population due to large losses due to waste.

Given that the consumption of fruits is below the recommended, that there are significant losses of fruits in post-harvest processing and the demand for fruit pulp is high, it is necessary to prioritize studies and investments in technologies to reduce this waste without increasing the cost to the consumer and offer products with nutritional quality (Mason-D'Croz et al., 2019; Storey & Anderson, 2018).

Processing fruit into frozen pulp aids in preventing waste from post-harvest losses. The loss of banana, for example, can reach up to 40% (Ssennoga, Mugurusi, & Oluka, 2019).

Knowledge about the physical and chemical properties of frozen fruit pulp is important for improving processing and storage conditions (Orqueda et al., 2021). Although the frozen fruit pulp market is growing, little information about physical and chemical properties is available in the literature.

The physicochemical characteristics are related to the quality of the fruit pulp and must meet a standard of current legislation. Freezing aims to preserve food for long periods, but even at temperatures below 0 °c changes can occur. Freezing speed and temperature stability during storage are related to physicochemical changes in food (Damiani, Lage, et al., 2013).

For better conservation of pulps it is recommended to store at a temperature between -18 ºC to -22 ºC (Mata et al., 2005). However, often this temperature is not maintained at the points of sale, as can be verified in the study of Feitosa et al. (2017) in which acerola pulp and tamarind were stored at a temperature between -2.4 ºC to -11.4 ºC, storage at inadequate temperatures can stimulate chemical and enzymatic activity in pulps.

After conducting an investigation in the literature has not been found to date studies on the rheological and physicochemical properties of frozen banana pulp. Based on the above, this study aimed to verify the effect of psyllium addition on color, rheology, pH and TTA parameters in frozen banana pulp during 90 days of storage under different temperatures (- 8 ° C and – 18 °C).

2. Methodology

2.1 Material

A banana (*Musa* spp.) of the cultivar "Prata" with natural ripening in the stage of maturation number 6 (Von Loesecke,1950) and psyllium (95% purity with 80% dietary fiber), were acquired in the local market in the municipality of Iguatu/CE. Citric acid (INS 330) and ascorbic acid (INS 300) were acquired with Pantec-Aditivos e Ingredientes Brasil Ltda.

2.2 Preparation of samples

The bananas were sanitized in running water and left in a chlorinated solution at 200 ppm for 15 minutes, rinsed and after natural drying the peels were removed. The bananas were placed in a depulper (Braesi brand model DES-60/1) and then the other ingredients were added according to Table 1. Ascorbic acid and citric acid were used to prevent enzymatic darkening and assist in product conservation (Brazil, 2013).

Table 1. Formulation of frozen banana pulp

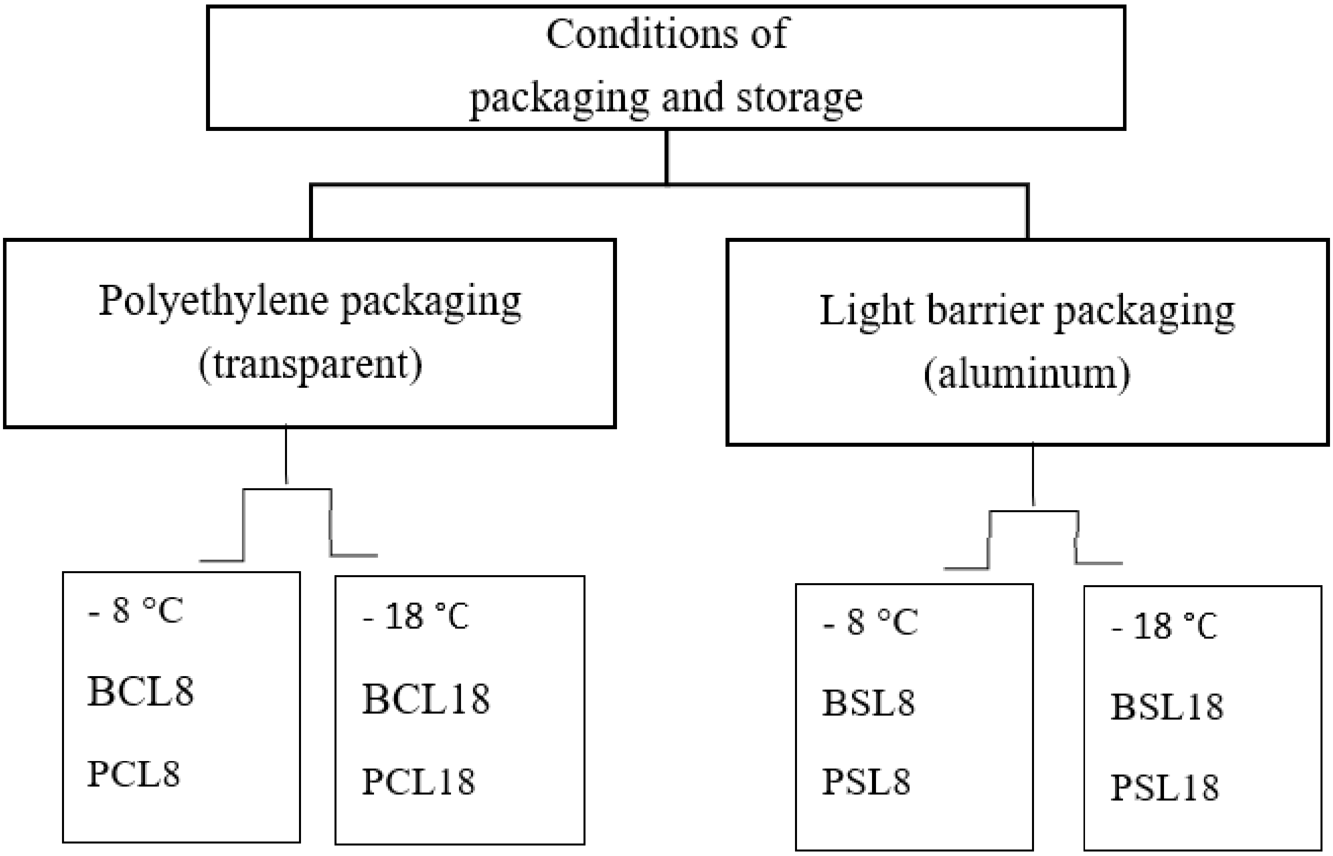
Sample	Psyllium	Banana	Citric acid	Ascorbic acid
Pulp 0%	0	99,6%	0,2%	0,2%
Pulp 3%	3%	96,6%	0,2%	0,2%

Source: Authors.

The pulps were packed and stored in two temperature conditions (- 8 °C and – 18 °C) and packaging (with barrier and without barrier to luminosity), as shown in Figure 1. All pulps were packaged in transparent plastic packaging (medium density polyethylene, average thickness of 0.117±0.001 mm), and to verify if the light would have any effect on the color of the pulps, aluminum foil (thickness 0.2 mm) was used to wrap and block the action of light. The pulps remained stored at temperatures of - 8 °C (to simulate a home freezer or freezer in commercial stores) and - 18 °C (to simulate a storage in industry). Triplicate Analyses occurred at times 0 (24 h); 30; 60; 90 days of storage.

The pulps were thawed at room temperature for 1 hour before performing the analysis.

Figure 1. Flow chart of packing and storage conditions of psyllium added banana pulp



Legend of pulps:
BCL8: - Banana with light (transparent packaging) - + 8 °C; BCL18: - Banana with light (transparent packaging) - 18 °C, BSL8 Banana with no light (aluminum packaging) - + 8 °C; BSL18 Banana with no light (aluminum packaging) to 18 °C; + PCL8: Psyllium, with the light (transparent packaging) - + 8 °C; PCL18: Psyllium, with the light (transparent packaging) - 18 °C-PSL8: Psyllium, with no light (aluminum casing) – + 8 °C; PSL18: Psyllium, without the light (aluminum casing) - 18 °C. Source: Authors.

2.3 The pH measurement

The determination of pH was performed by immersion of the pH meter electrode (LUCADEMA) in each sample up to the pH remains constant (Instituto Adolfo Lutz, 2008).

2.4 Titratable Total Acidity (TTA)

1.0 g of each sample was weighed in a 250.0 beaker mL and dissolved in 50.0 mL of distilled water and in then stirred with a magnetic stirrer (MARTE AY-220) until complete dissolution of the sample. Then the titration with 0.1 M sodium hydroxide solution to a pH range between 8.2 to 8.4 which was measured through pHmeter (INSTITUTO ADOLFO LUTZ, 2008).

2.5 Color determination

The instrumental color determination of the samples was performed using colorimeter Chroma Meter CR-400 (Konica Minolta, Japan), using illuminant D65 and geometry 45/0, and the color values were expressed in the CIELAB system. The values of *L* *(Luminosity), a* (red-green component) and b* (yellow-blue component) were obtained directly from the colorimeter. *L* * ranges from 0 to 100, in which the value 0 indicates black (or dark color) and 100, white (light color). All measurements were carried out at a temperature of 20 °C under the same light conditions (measuring area of 50 mm^2 per measurement) and replicated 6 times (Lawless; Heymann, 1998).

2.6 Rheological properties

The rheological behavior of the pulps was determined by a rotational rheometer of concentric cylinders type Searle Brookfield, model R / S plus SST 2000. The measurements were made at a temperature of 25 ºC (Amaral et al., 2018). The equipment provided the shear voltage and strain rate data through RHEO V 2.8 software. Rheological analyses were obtained with variation of the deformation rate from 0 to 200 s-1 (ascending curve) and from 200 to 0 s-1 (descending curve), with a time of 1 minute and reading of 25 points for each curve. The readings were made in triplicate and in each measure a new sample was used. The data obtained in the rheological analysis were adjusted to the models of Newton, Ostwald-De-Waelle, Herschel Bulkley, Casson, modified Casson, Sisko, Cross and Carreu (Table 2).

Table 2. Models used to evaluate rheological behavior.

Model name	Code	Equation
Newton	Mod1	$\tau = \eta(\dot{\gamma})$
Ostwald-De-Waelle	Mod2	$\tau = k(\dot{\gamma})^n$
Herschel Bulkley	Mod3	$\tau = \tau_o + k_H(\dot{\gamma})^{n_H}$
Casson	Mod4	$(\tau)^{0.5} = k_{oc} + k_{cass}(\dot{\gamma})^{0.5}$
Modified Casson	Mod5	$(\tau)^{0.5} = (k_{oc})^{0.5} + k_{cass}(\dot{\gamma})^n$
Sisko	Mod6	$\tau = \mu_\infty \dot{\gamma} + K(\dot{\gamma})^n$

Where: τ = shear stress (Pa), η= is the behavior index (dimensionless), ẏ= deformation rate (s^{-1}**)**, K = Consistency Index (Pa.s), n= behavior index (dimensionless),τ = shear stress (Pa),□□$_0$= flow stress, K_H = Herschel Bulkley Consistency Index,γ = deformation rate (s-1), K_{oc}= initial stress (Pa), K_{cass}= Casson plastic viscosity (Pa.sn), µ= absolute viscosity, μ_0-zero deformation viscosity, μ_∞ - infinite deformation viscosity. Source: Authors.

2.7 Data Analysis

ANOVA was used to verify the difference between the samples, and where there was a difference, the T-test was performed using the significance level of 5%. Mathematical models for adjusting viscosity curves were tested to describe the rheological behavior of the samples. As reported by Spies et al. (2010) R^2 neither the adjusted R^2 are suitable for evaluating nonlinear models. Thus, the mathematical models were evaluated using the Akaike information Criterion (AIC), which evaluates the model residues. Following the same criterion of the smallest residues of the model, Root-mean-square deviation (RMSE) was also used. The models that presented lower values of AIC and RMSE were considered the best. All statistical calculations were analyzed using R software (programming language for Computational Statistics).

3. Results and Discussion

There were physicochemical changes during the storage of frozen banana pulps added from psyllium.

Knowing the physicochemical changes during the storage of products is important to establish the commercial validity of the same. Minor amendments may be considered acceptable, provided they meet the requirements of current legislation.

For storage in the absence of light, it was verified that there were no significant changes in the tested temperatures for the color, rheology, pH and acidity parameters when compared to pulps packed in transparent material, for this reason the following results will not include this information, since to make it possible to market the transparent packaging (not laminated) is more interesting to be used, since it has lower cost.

The results of the study by Barros Monteiro, & Pires (2017) analyzing the stability of murici jelly in different storage conditions corroborate the findings of this research. The authors found that the jelly stored in the presence of luminosity did not present a significant difference for the analysis of pH, TTA and color (L*, a* and b*) compared to the jelly stored in the absence of luminosity.

3.1 Titratable Total Acidity and pH

The results for pH are shown in Table 3. It is observed that the pH showed significant changes for all samples during the storage period, but did not show significant difference between the different temperatures within the same formulation.

Table 3. pH of frozen banana pulp within 90 days of storage in transparent packaging

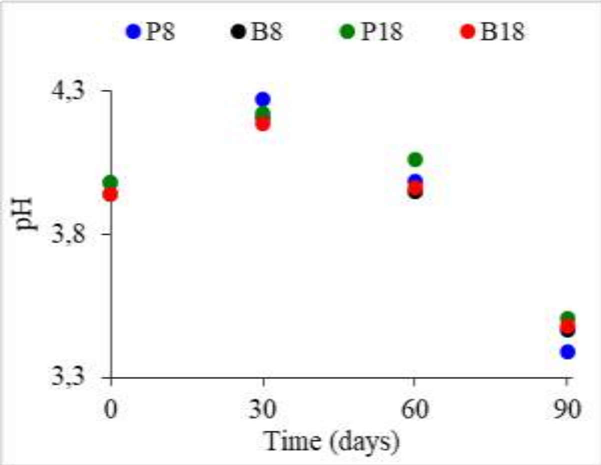
Sample (*)	Time / pH			
	24 hours	30 days	60 days	90 days
B8	3.94 ± 0.05 $^{B;a}$	4.21 ± 0.02 $^{A;b}$	3.95 ± 0.04 $^{B;b}$	3.46 ± 0.05 $^{C;a}$
B18	3.94 ± 0.05 $^{B;a}$	4.19 ± 0.02 $^{A;b}$	3.96 ± 0.01 $^{B;b}$	3.48 ± 0.07 $^{C;a}$
P8	3.98 ± 0.01 $^{B;a}$	4.27 ± 0.02 $^{A;a}$	3.99 ± 0.03 $^{B;a}$	3.39 ± 0.08 $^{C;a}$
P18	3.98 ± 0.01 $^{C;a}$	4.22 ± 0.03 $^{A;a}$	4.06 ± 0.04 $^{B;a}$	3.50 ± 0.02 $^{D;a}$

Different capital letters on the same line indicate significant difference by the T-test for unpaired samples. Different lowercase letters in the same column indicating significant difference by the T test for unpaired samples. All analyses were performed at a significance level $p < 0.05$. (*): B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8= banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

It can be seen in Table 3 that the addition of psyllium left the pH more stable during the storage period, when checking the pH of the pulps without the addition of psyllium we noticed an instability and a reduction in pH at the end of the storage period.

The pH of the pulps did not remain stable during storage. The kinetics of pH in relation to time can be verified in Figure 2. It is observed that both the banana pulp and the added pulp of psyllium presented a similar pattern during storage at both temperatures.

Figure 2. Kinetics between pH and storage time of frozen banana pulp



B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8= banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

Figure 2 shows that all treatments presented PH reduction at the end of the storage period and remained within the desirable range (< 4.5) throughout the storage period, thus preventing the proliferation of microorganisms. According to Tan, Misran, Daim, Ding, & Pak Dek, (2020), pH is an important attribute that can be used to determine the quality, freshness and taste of fruits and low pH tends to reduce microbial growth.

Similar results regarding pH reduction during storage period of fruit pulp were found by Orqueda et al. (2021) analyzing chilto pulp stored at - 18 °C during storage period of 180 days. The same result was obtained by Damiani et al. (2013) analyzing marolo pulp stored under freezing - 18 °C for 12 months.

However, when analyzing the studies of Tan et al. (2020) it was verified that after the storage of durian pulp (fruit from Southeast Asia) for 12 months the pH and total titratable acidity showed no changes.

An explanation for these results may be in the method chosen for freezing, since in the study of Tan et al. (2020) with durian pulps was used rapid freezing (- 40 °C for 4 hours and storage under – 20 °C) and in studies by Orqueda et al. (2021) with the pulps of chilto and Damiani et al. (2013) with marolo pulps it was verified that the freezing was carried out by the slow method. It is suggested that the chosen freezing method may be related to pH stability and titratable total acidity.

According to the studies of Jha & Jury (2019) the method chosen to freeze fruits and vegetables may be related to the disruption of cell membranes, because the growth of ice crystals in the slow freezing method (- 18 °C) pierces the membrane, leading to tissue breakdown and release of degrading enzymes. These enzymes can degrade polysaccharides (pectins and hemicelluloses) during thawing by releasing organic acids. Some fruits are more susceptible to freeze damage, and banana is one of them (Wang, 1990) .

As Ahmad, Khan, & Ayub (2000) the pH reduction in frozen fruits and vegetables may be related to pectin hydrolysis or polysaccharide degradation (Ahmad et al., 2000).

Despite the changes in pH, acidity remained stable for almost the entire storage period as can be seen in Table 4.

Table 4. Titratable total acidity (% malic acid) in frozen banana pulp stored for 90 days

Sample (*)	Time / TTA			
	24 hours	30 days	60 days	90 days
B8	0.99 ± 0.01 A; a	0.99 ± 0.01 A; a	0.98 ± 0.01 A;a	0.98 ± 0.01 A;a
B18	0.99 ± 0.01 A; a	1.00 ± 0.01 A; a	0.99 ± 0.01 A; a	0.99 ± 0.01 A; a
P8	1.02 ± 0.01 A; a	1.01 ± 0.01 A; a	0.98 ± 0.01 B; a	0.95 ± 0.01 C; b
P18	1.02 ± 0.01 A; a	0.99 ± 0.01 B; a	0.98 ± 0.01 B; a	0.94 ± 0.01 C; b

Different capital letters on the same line indicate significant difference by the T-test for unpaired samples. Different lowercase letters in the same column indicating significant difference by the T test for unpaired samples. All analyses were performed at a significance level $p < 0.05$. (*) B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8 = banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

In Table 4 it is possible to verify that the pulps without the addition of psyllium remained with stable acidity throughout the storage period, it is noted that in the last month the pulps with the addition of psyllium presented a small reduction in acidity.

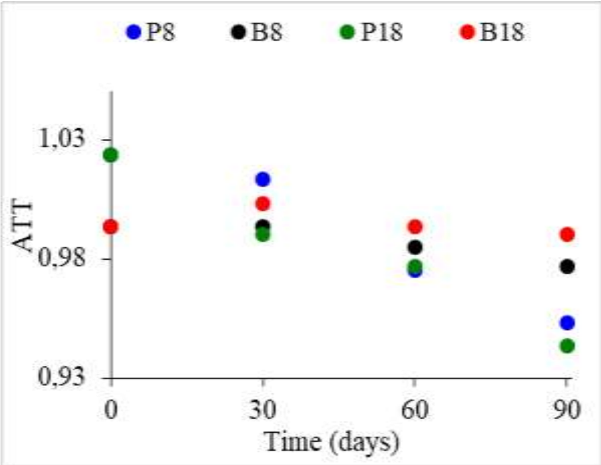
It can be noted that the storage temperature did not interfere with the acidity results.

Similar results were observed in studies of Tan et al. (2020) with durian pulp, unpasteurized and without addition of acidulants, under freezing at - 20 °C for 12 months it was observed that the acidity remained constant during the storage period.

Banana pulp added with psyllium showed reduced acidity during the storage period.

It is possible to observe in Figure 3 the kinetics of acidity in relation to time. Despite the reductions in acidity in banana pulp added psyllium can be verified that meets the recommended by current legislation. According to normative instruction n° 37 of 10/2018, the identity and quality standards for banana pulp should be of minimum total acidity of 0.20 (g / 100 g) (Brazil, 2018), and the pulps of this study presented values greater than 0.94.

Figure 3. Kinetics between acidity and storage time of frozen banana pulp



P8 = banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C; B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C. Source: Authors.

The reduction of Titratable Total acidity in added psyllium pulps can be explained by the acid hydrolysis of polysaccharides (dietary fiber) present in the structure of psyllium. Zhang, Wen, Zhang, & Duan (2019) they stated that glycosidic bonds in psyllium polysaccharides can be broken by acid hydrolysis. According to the authors, there are few discussions in the literature about the relationship between the structure of psyllium polysaccharide and its biological activity.

In a study with yogurt, it was observed that the addition of psyllium caused a reduction in total titratable acidity during refrigerated (Bhat, Deva, & Amin, 2018)storage corroborating with the results of this study.

3.2 Color determination

Color is an important indicator of quality and can interfere with the acceptance of the product by the consumer (Orqueda et al., 2021). The luminosity parameters (*L**) of the pulps were checked and are shown in Table 5.

Table 5. Results for determination of *L** of frozen banana pulp for 90 days storage

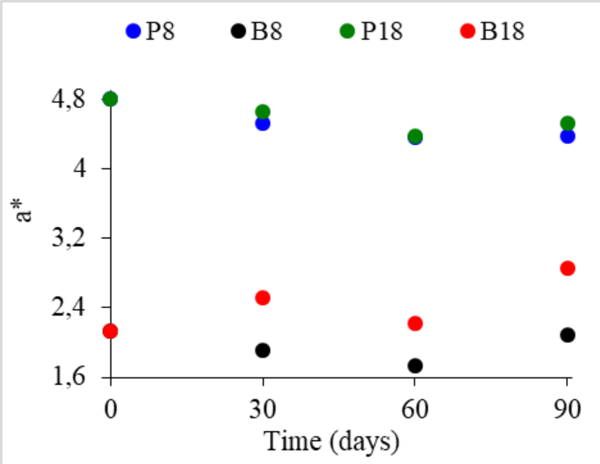
Sample (*)	Time / (*L**)			
	24 hours	30 days	60 days	90 days
B8	71.5 ± 0.57 A;a	71.24 ± 0.22 A;a	71.82 ± 0.2 A;b	67.89 ± 0.16 B;b
B18	71.5 ± 0.57 A;a	71.8 ± 0.13 A;a	73.14 ± 0.08 A;a	72.47 ± 0.21 A;a
P8	64.27 ± 0.19 A;b	62.67 ± 1.48 AB;b	62.41 ± 0.38 A;d	61.29 ± 0.12 B;d
P18	64.27 ± 0.19 A;b	64.61 ± 0.48 A;b	65.04 ± 0.33 A;c	63.23 ± 0.62 B;c

Different capital letters on the same line indicate significant difference by the T-test for unpaired samples. Different lowercase letters in the same column indicating significant difference by the T test for unpaired samples. All analyses were performed at a significance level $p < 0.05$. (*) B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8 = banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

Table 5 shows that the pulp color remains stable during the 60 days of storage, it is possible to verify that the addition of psyllium caused a change in the pulp color pattern.

The addition of psyllium caused a significant change in the color of the pulp reducing the luminosity (*L**), that is, the product darkened and also caused a change in the values of a*, tending to a more red color (Table 5 and Figure 4).

Figure 4. Kinetics of parameter a* in relation to the storage time of frozen banana pulp.



B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8 = banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

Regarding time, it is noticed that up to 60 days of storage all the pulps maintained stable luminosity. This suggests that the use of acidulants were efficient to inactivate oxidative enzymes. For the temperature, it was observed that it did not interfere with the luminosity for 30 days, but from this time there were significant differences.

A similar result in relation to banana pulp without the addition of psyllium was verified in the study of Yap, Fernando, Brennan, Jayasena, & Coorey (2017) banana puree preparation at maturation stage 6. They performed the bleaching and adjusted the pH to 4.0 with citric acid (0.5 mol / L) obtaining a luminosity (*L**) of the puree of 68.91.

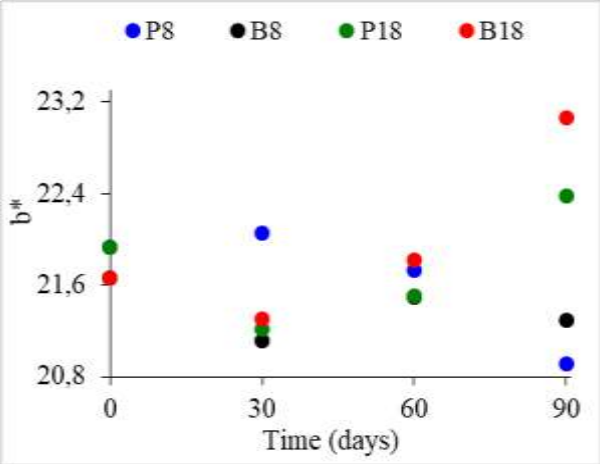
It is possible to verify from Figure 4 that the addition of psyllium affected the parameter a*, the pulps with psyllium presented higher values in this parameter and can be justified due to the psyllium having a more reddish color than the banana.

In the studies of Krystyjan, Gumul, Korus, Korus, & Sikora (2018) with psyllium-fortified biscuits significant change in color characteristics was observed similar to this study, the authors reported that there was a decrease in luminosity (*L**). In another study with added psyllium biscuits, a darkening with a reduction in *L* * values was also observed (Raymundo, Fradinho, & Nunes, 2014).

The explanation for the luminosity reduction (*L**) at 90 days of storage for pulps at temperature – 8 °C may be related to carotenoid degradation.

As shown in Figure 5 it is observed that time and temperature had effect on the parameter b* of banana pulp. Parameter b* is related to yellow pigments (carotenoids). Carotenoids (α-and β-carotene) are the largest responsible for the coloring in the banana, a greater yellow coloring of the pulp indicates an increasing level of carotenoids (Englberger et al., 2010).

Figure 5. Kinetics of parameter b* in relation to the storage time of frozen banana pulp.



B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8 = banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

It can be seen from Figure 5 that there was a change in the parameter b* after 60 days of storage for both temperatures, it is possible to observe that the pulps stored at a temperature of – 8 °C had the values of b* reduced at the end of storage and the pulps stored at – 18 °C had the values of b* increased.

In a study with frozen cherries it was verified that the freezing method can provide enzymatic reactions, the authors reported that slow freezing caused the rupture of cell membranes, which allowed enzymatic interactions with the substrate during thawing causing darkening in Cherries (Bilbao-Sainz et al., 2019).

In this study the pulps were frozen at temperatures of - 8 °C and - 18 °C, that is, the pulps from freezing at – 8 °C took longer to freeze completely compared to the pulps that were frozen at – 18 °C and this may have caused a lesion in the membranes and allowed enzymatic reactions. According to Énicaud, Chir, Ayer, Ornier, & Ohuon (2011) the slow freezing pierces the cell membranes, releases the oxidant enzymes present in the tissues and allows the interactions of the enzymes with the air during thawing.

Tan et al. (2020) investigating the effects of freezing on durian pulps found that after 12 months the pulps showed a reduction in *L** possibly due to changes in concentrations of carotenoid pigments that were gradually lost during low-temperature storage.

Darkening by degradation of carotenoids occurs by several pathways and enzymatic oxidation is one of them. Enzymes are not completely inactivated during frozen storage and enzymatic reactions may occur slowly due to the presence of available unfrozen water. According to the authors another condition that influences the degradation of carotenoids are the organic acids released during processing that are sufficient to promote rearrangements in carotenoids (Énicaud et al., 2011).

3.3 Rheological characteristics

Among the models tested to describe the rheological behavior of pulps, the Casson model had a better fit with lower values of AIC and RMSE and was considered the indicated. According to Silva et al. (2012) the Casson model is suitable for describing non-newtorian fluids with suspended particles.

Casson model described well the behavior of banana pulp in relation to the other models and for this reason this model was used to determine the rheological parameters in this study.

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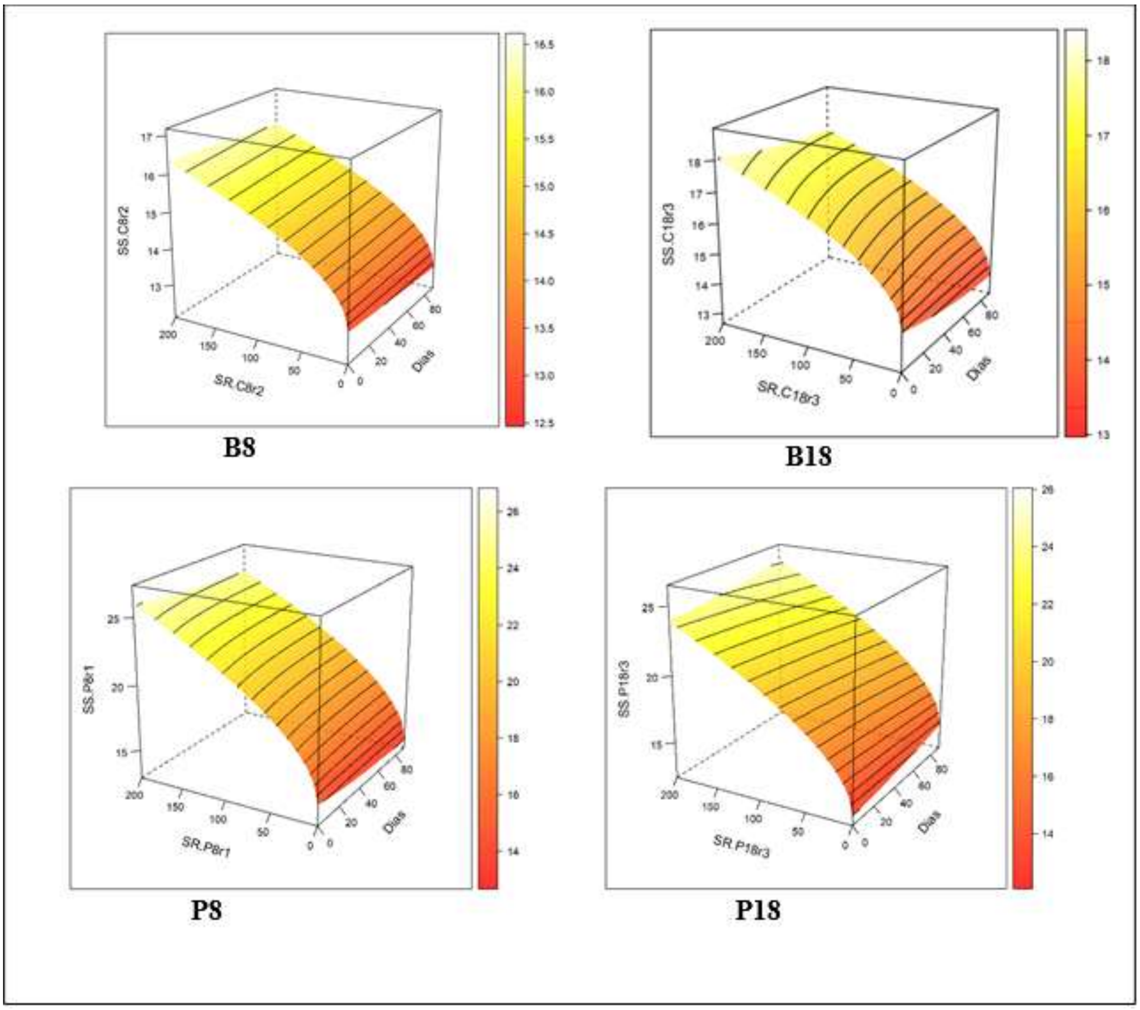
Melo et al. (2020) when analyzing the rheological behavior of cupuassu pulp, they reported that the Casson model can be used in the evaluation of rheological parameters for this pulp. Guerrero & Alzamora (1997) they also used this model to analyze the rheological behavior of fruit purees.

Figure 6 shows the behavior of pulps under storage for 90 days. As can be seen, the pulps showed similar behavior in all treatments. It appears that the behavior of the banana pulps is similar to the behavior of the pulps added with psyllium.

It can be confirmed by Figure 6 the non-Newtonian behavior with pseudoplastic flow curve of all pulps, regardless of time, temperature and addition of psyllium, as verified the slopes of the flow curves reduced with the increase of shear stress revealing the decrease of the apparent viscosity. It is observed in the graphs that the storage time had little effect on the rheological behavior of the pulps.

Figure 6. Flow curves shear stress versus shear rate of banana pulp under frozen storage (- 8 °C and – 18 °C) for 90 days.



B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8 = banana pulp with psyllium stored at -8 °C; P18 = banana pulp with psyllium stored at -18 °C. Source: Authors.

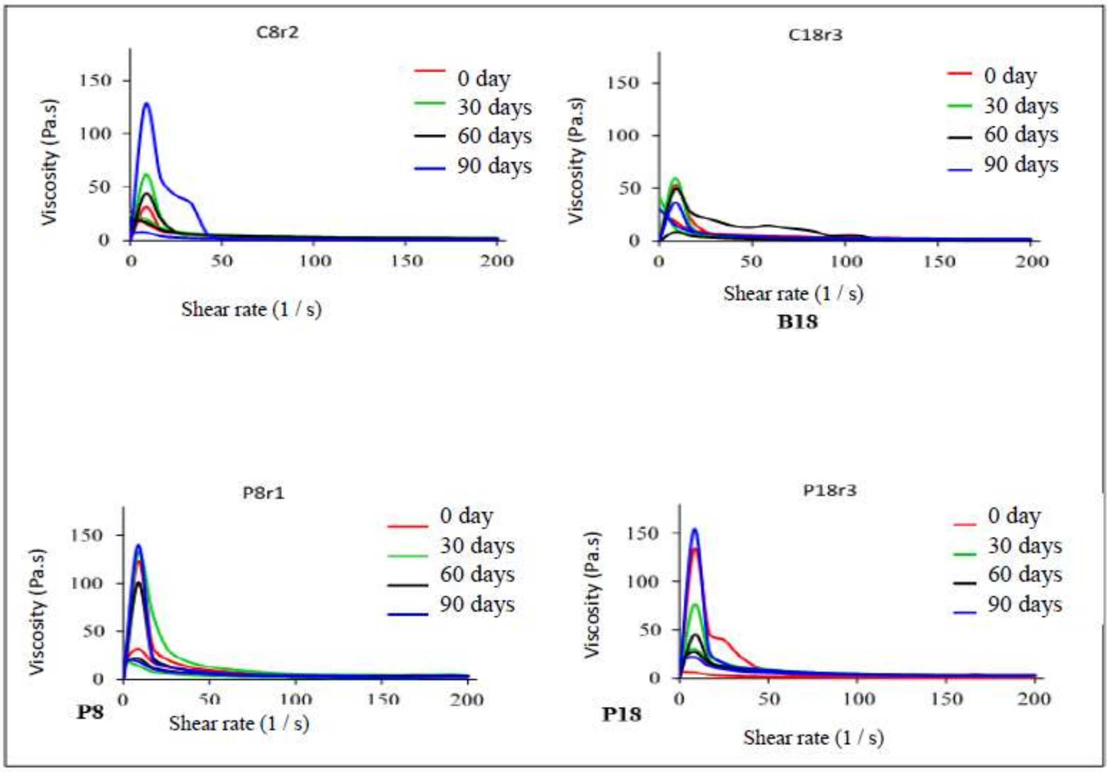
In the study by Melo et al. (2020) cupuassu pulp also showed pseudoplastic behavior. According to the authors as the shear stress force is applied on the fluid, the solid particles are ordered in the direction of the flow, and this causes the reduction in apparent viscosity and reduction of flow resistance.

Green banana pulp was added in an oil-water emulsion (mayonnaise) and the results corroborated with the result of this study. Izidoroe, Scheer, Sierakowski, & Haminiuk (2008) when studying the influence of green banana pulp on the rheological behavior of emulsions (mayonnaise), they verified that the emulsions revealed a pseudo-plastic behavior, since the values of the flow behavior index (*n*) were less than 1 (*n* <1.

The characteristic of pseudoplasticity in the studied pulps is explained by the presence of suspended solids present in all pulps. As reported by Guerrero & Alzamora (1997) fruit purees that have pseudo-plastic behavior are due to the results of complex interactions between soluble sugars, pectic substances, and suspended solids.

The graphs of apparent viscosities versus shear rates are shown in Figure 7. The outward curves presented higher apparent viscosity than the inward curves, a result of the force that was generated and applied to the pulp with a breakdown of the structure of the molecules and reduction of viscosity.

Figure 7. Apparent viscosity of frozen banana pulp under Storage - 8 °C and - 18 °C, for 90 days.



B8 = banana pulp stored at -8 °C; B18 = banana pulp stored at -18 °C; P8 = banana pulp with *psyllium* stored at -8 °C; P18 = banana pulp with *psyllium* stored at -18 °C. The highest curve of the same color indicates "going curve "and the lowest indicates "back curve". Source: Authors.

The apparent viscosity of all samples decreased with increasing shear rate. It was verified that fruit pulp tends to present this behavior, as verified in the study of Chen et al. (2020) with strawberry pulp and Y. Liu et al. (2019) with mango pulp.

This behavior can be explained by the hydrodynamic forces that are generated causing the structural breakdown of the molecules and providing the alignment of the constituent molecules resulting in low viscosity (Alpaslan & Hayta, 2002).

It is observed from Figure 7 that the addition of psyllium increased the viscosity of the pulps (P8 and P18) regardless of the storage temperature. Psyllium has higher fiber content and therefore has higher apparent viscosity. Similar result was observed with the addition of psyllium in yogurt, the authors reported an increase in apparent viscosity in yogurts with higher concentrations of psyllium (Ladjevardi, Gharibzahedi, & Mousavi, 2015)

According to studies of Pelegrine, Vidal, & Gasparetto (2000) whole pulps (mango and pineapple) have higher fiber content and have higher viscosity.

Chen et al. (2020) when verifying the rheological properties of strawberry pulp, they reported that the interactions of hemicellulose, starch, cellulose and lignin can cause changes in viscosity.

The apparent viscosity of the banana pulp at-8 °C differed from the pulp at - 18 °C at the end of the storage period. This result may be related to the disruption of the cell wall (during freezing) and the release of pectin (during thawing). According to the results of Van Buggenhout et al. (2015) with orange pulp, cell wall rupture can increase pectin exposure and increase apparent viscosity. Zhou et al. (2017) when studying the rheological behavior of mango pulp, they reported that the pectin molecules released by the rupture of cell membranes lead to increased pulp consistency.

Viscosity is an important quality control parameter that allows you to evaluate variations in processing and storage conditions and can estimate the consistency of the final product. According to Crispín-Isidro et al. (2015) soluble fibers can improve creaminess and acceptance in some products.

4. Conclusion

Psyllium changed the pH and TTA of frozen banana pulp, but meets the recommended quality and identity standard provided for in legislation.

It changed the color (*L* * and a*) and increased the apparent viscosity, which can be a differential for the pulp, providing more creaminess to the final product.

Frozen banana pulp can be produced with the addition of psyllium and among the tested temperatures it was found that at-18 °C they maintain the physicochemical parameters (pH, Total acidity, color and rheological characteristics) suitable for up to 60 days and for storage at - 8 °C the commercial validity is reduced, but viable for up to 30 days.

This pulp containing 3% psyllium addition (equivalent to 3 g) in one serving can receive on its label the claim of health being a competitive differential in the market. The addition of psyllium to banana pulp is an innovative way to generate a product with desirable properties to meet the needs of consumers.

Finally, further studies are needed in order to verify consumer acceptance of frozen and stocked pulp.

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