COMPARATIVE ANALYSIS OF INDUSTRIAL AND HOMEMADE STRAWBERRY JAM PROCESSING: QUALITY, DEGRADATION, AND ENERGY CONSUMPTION

Bruna Ester Dias de Cara ¹  
Daisy Naomi Tan ²  
Sheila Oliveira-Alves ³  
Marcelo Alexandre Prado ⁴  
Flávio Luís Schmidt ⁵

ABSTRACT

Purpose: Compare certain steps of strawberry jam processing, energy consumption, waste generation, as well as indicators of jam quality obtained through industrial and homemade methods.

Method/design/approach: The jams were prepared in the fruit and vegetable laboratory as well as in the pilot plant. The bottling process involved hot sealing in glass jars with metal lids. After sealing, the jars were inverted, cooled, and stored at -18 °C until analysis. The ingredients used included high methoxyl pectin, citric acid, sucrose, and fresh acidic lemon juice. The analysis included the use of various chemicals such as methanol, sodium acetate, potassium chloride, hydrochloric acid, NaOH, ascorbic acid, dihydrated oxalic acid, and 2,6-dichloroindophenol.

Results and conclusion: The study examined industrial, semi-industrial, and homemade jams, highlighting changes in color parameters and losses of anthocyanins and ascorbic acid over time. Homemade jams exhibited greater variations in both color and processing. Strawberry pre-processing and water consumption differed between industrial and homemade productions, with a higher disposal rate observed in industrial production. The yield of industrial jams remained consistently above 90%, whereas homemade jams showed variations. Energy consumption was higher in homemade jams, making the industrial process more energy-efficient. Industrial vacuum processing provided advantages such as lower temperatures, reduced sensible heat, and minimized chemical changes, but it necessitated more expensive and maintenance-intensive equipment.

Originality/value: In contemporary discourse, there has been substantial censure directed towards industrialized foods in recent years, with a considerable portion lacking a rigorous scientific foundation. This study contributes by presenting findings that facilitate the discernment of advantages stemming from both industrial and artisanal processes, contingent upon the availability of requisite technical knowledge.

Keywords: Strawberry Jam, Industrial Processing, Homemade Processing, Comparative Analysis, Quality Indicators, Energy Consumption.

¹ Universidade Estadual de Campinas, Campinas, São Paulo, Brasil. E-mail: bruedias22@gmail.com  
Orcid: https://orcid.org/0000-0003-1008-2070

² Universidade Estadual de Campinas, Campinas, São Paulo, Brasil. E-mail: dnaomi20@gmail.com  
Orcid: https://orcid.org/0000-0002-6260-3793

³ Instituto Nacional de Investigação Agrária e Veterinária, Quinta da Almoína, Dois Portos, Portugal. E-mail: sheilacris.oliveira.alves@gmail.com  
Orcid: https://orcid.org/0000-0002-9963-4673

⁴ Universidade Estadual de Campinas, Campinas, São Paulo, Brasil. E-mail: mprado@unicamp.br  
Orcid: https://orcid.org/0000-0002-1635-911X

⁵ Universidade Estadual de Campinas, Campinas, São Paulo, Brasil. E-mail: schmidt@unicamp.br  
Orcid: https://orcid.org/0000-0002-3287-8630
ANÁLISE COMPARATIVA DO PROCESSAMENTO INDUSTRIAL E CASEIRO DE GELEIA DE MORANGO: QUALIDADE, DEGRADAÇÃO E CONSUMO DE ENERGIA

RESUMO

Objetivo: Comparar determinadas etapas do processamento de geleia de morango, o consumo de energia, a geração de resíduos, bem como indicadores de qualidade da geleia obtidos por métodos industriais e caseiros.

Método: As geleias foram preparadas no laboratório de frutas e vegetais, assim como na planta piloto. O processo de envase incluiu o fechamento a quente em potes de vidro com tampas metálicas. Após o fechamento, os potes foram invertidos, resfriados e armazenados a -18 °C até a análise. Os ingredientes utilizados foram pectina de alta metoxilação, ácido cítrico, sacarose e suco fresco de limão ácido. A análise envolveu o uso de diversos produtos químicos, como metanol, acetato de sódio, cloreto de potássio, ácido clorídrico, NaOH, ácido ascórbico, ácido oxálico di-hidratado e 2,6-dicloroindofenol.

Resultados e conclusão: O estudo analisou geleias industriais, semi-industriais e caseiras, destacando mudanças nos parâmetros de cor e perdas de antocianinas e ácido ascórbico ao longo do tempo. Geleias caseiras mostraram variações maiores na cor e no processamento. O pré-processamento de morangos e o consumo de água diferiram entre produções industriais e caseiras, com uma taxa de descarte maior na produção industrial. O rendimento das geleias industriais foi consistente acima de 90%, enquanto as caseiras variaram. O consumo de energia foi maior nas geleias caseiras, tornando o processo industrial mais eficiente energeticamente. O processamento a vácuo industrial ofereceu vantagens, mas requer equipamentos mais caros e exigentes em manutenção.

Originalidade/valor: No discurso contemporâneo, tem havido uma substancial censura dirigida aos alimentos industrializados nos últimos anos, com uma parte considerável carente de uma base científica rigorosa. Este estudo contribui apresentando descobertas que facilitam o discernimento de vantagens decorrentes tanto de processos industriais quanto artesanais, dependendo da disponibilidade do conhecimento técnico necessário.


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1 INTRODUCTION

In urban centers, supermarkets are the most common places to obtain food. However, it is sometimes possible to prepare various foods at home using raw materials. These options are linked to discussions guided by different knowledge areas, such as social, economic, food, and environmental sciences. From a technological perspective, food processing involves many factors, including quality assurance through established standards, which can be justified by industry and consumer objectives and should also involve public health aspects (Rahmat et al., 2016).

Food security is also an important concept in the context of food production. It exists when there is availability and physical and economic access to safe and nutritionally adequate food in sufficient quantities on a regular and permanent basis over time for all people. Food production is related to the availability of food and is influenced by factors such as production levels, stock, net trade, and sustainability of the food system without harming the environment (FAO, 2008; FAO, 2017). The industry must ensure that food safety and food security standards are not compromised and comply with regulatory and customer requirements (Rahmat et al., 2016).
Food processing involves a set of operations used to intentionally modify food under controlled conditions to ensure effective processing (Brennan et al., 1969; Floros et al., 2010; Fellows, 2018; Meijer et al., 2021; Knorr and Augustin, 2021). Regardless of industry criteria, it is important to understand the steps of food processing because a change in one parameter, such as thermal processing, can affect the characteristics of the final product. Studies conducted over the past few decades have focused on the degradation of important parameters related to consumer acceptance, nutritional aspects, and food safety. These studies explore factors such as color degradation over time and temperature during processing, which are related to the macro and micronutrients present in food, including the degradation of heat-sensitive vitamins (Morales and Aparicio, 1999; Apaiah and Barringer, 2001; Xu et al., 2015; Aghajanzadeh, Kashaninejad and Ziaifar, 2016; Martinsen, Aaby and Skrede, 2020).

These variables can occur in both industrial and home settings, resulting in different characteristics for the same product. However, it does not mean that one is inherently better than the other, although the perception that homemade preparations are superior is often based on misinformation spread through the media rather than scientific evidence (Petrus et al., 2021; Meyjer et al., 2021). The perception of the naturalness of food seems to be associated with traditional preparation techniques or the scale of production rather than the physical-chemical transformation (Etale and Siegrist, 2021).

Jam is an example of a product that can be prepared in both industrial and home methods. It was developed as a means of preserving fruit for an extended period (De Gregorio, 2007). Like any other food product, jam can be prepared using different methods, ingredients, quality standards, and production scales. The formation of the gel in jam depends on factors such as the presence of pectin (naturally occurring or added), soluble solids like sugar content, pH, and the presence of calcium salts depending on the type of pectin used (Jackix, 1988; Damodaran, 2010).

Whether made at home or in an industrial setting, jams are generally prepared through thermal concentration until reaching the desired consistency. In homemade preparations, the concentration point can vary significantly and is often determined subjectively based on the flow and viscosity of the mixture (Steer, 2010; Gondim, 2018). In industrial plants, the concentration step can be carried out under vacuum and at lower temperatures, but the process must still be standardized to ensure the quality of the gel formation, including pH control (Jackix, 1988; Hood, 2021).

In Brazil, approximately 75% of strawberry production is destined for table consumption (Iwassaki, 2010). The remaining portion is used by the industry to make jam, pulps, frozen strawberries, and other byproducts. The success of the jam preservation process is derived from the heat treatment (concentration), which reduces water activity, the low pH (approximately 3.2), hermetic closure (Jackix, 1988; Krolow, 2016), and sometimes the use of preservatives. However, like other fruit jams, the acceptable appearance of strawberry jam is related to the degradation of pigments, particularly anthocyanins, which are constituents associated with the health benefits of fruit consumption (Cassidy et al., 2010; Chaves, Calvete and Reginatto, 2017; Tobal and Rodrigues, 2019). Thus, during the thermal processing of strawberries for jam production, the concentration of heat-sensitive compounds, such as ascorbic acid and anthocyanins, can serve as indicators of the intensity of the process (Patras et al., 2011; Badin et al., 2020).

This study aims to evaluate different methods of preparing strawberry jam, with an emphasis on homemade and industrial methods, comparing them in terms of quality indicators and process parameters.
2 METHOD

All the jams were made using a mixture of frozen varieties of Camino Real, Benícia, San Andreas, and Senga Sengana strawberries, collectively referred to as M1. The only exception was the semi-industrial jam processed under vacuum in the pilot plant, which was made using only the Camino Real strawberry variety, referred to as M2. The strawberries were previously defrosted and immediately used at the time of preparation. For the tests involving water consumption and waste evaluation, strawberries obtained from the local market during the harvest and intercrop periods were used.

The ingredients and chemicals used included high methoxylpation pectin (105 rapid set, CP Kelco), citric acid P.A. (Dinâmica), commercial sucrose, and acid lime fresh juice (Citrus latifólia) from the local market. The analysis involved the use of methanol, sodium acetate (Synth), potassium chloride, hydrochloric acid, NaOH, ascorbic acid, oxalic acid dihydrate (Dinâmica), and 2,6-dichlororindophenol (DCFI) (ACS).

The homemade and semi-industrial pilot plant jams were produced in the fruit and vegetable laboratory and pilot plant, respectively, at the School of Food Engineering of Campinas State University. All jams were hot-filled into glass pots and closed with metal caps. After closing, the pots were inverted for 5 minutes, returned to their original position, cooled to room temperature, and then frozen at -18 °C until analysis or stored in a dark place.

The industrial jams were obtained from a fruit processing industry and were divided into those processed under vacuum and those processed under atmospheric pressure.

Table 1 presents the list of ingredients for the Industrial, Semi-industrial, and Homemade jams. Figure 1 illustrates how each volunteer decided to process their own jam, including burner power, end point, and consequently, the processing time.

2.1 Industrial Jam

The industrial jam was processed in two different ways: concentrated under vacuum (I1) at 80-90 °C for 25 minutes, or concentrated under atmospheric pressure (I2) for 40 minutes at approximately 100 °C. The recipe used a 1:1 ratio of strawberry to sucrose, and acidification was achieved by using concentrated acid lime juice (I1) or citric acid (I2) until the pH reached 3.2. The process steps involved pre-mixing the ingredients, concentration, pump transport to the tank storage, and hot filling line. Unfortunately, it was not possible to obtain the jam immediately after processing, so both I1 and I2 were acquired 14 days and 62 days after processing, respectively, and kept in cardboard boxes until retrieval from the company.

2.2 Semi-Industrial Pilot Plant Jam

The semi-industrial pilot plant jams were prepared using a 1:1 ratio of strawberry to sucrose, citric acid (determined by titration curve of homogenized strawberry) until the pH reached 3.2, and pectin. Some water was added to dissolve and hydrate the pectin beforehand (70 °C/5 minutes). The concentration step was carried out either under vacuum (referred to as P1) at 85 °C until reaching 60 °Brix, using a 50-liter ICMA vacuum jacketed vessel heated with steam, or under atmospheric pressure (referred to as P2) at approximately 100 °C until reaching 60 °Brix, using a 60-liter ICMA jacketed vessel heated with steam, in approximately 30 minutes.
2.3 Homemade Jam

The homemade jam was prepared using a popular recipe (Panelinha, 2000) with a higher fruit content (64% of fruit, referred to as H1) or a content similar to industrial or semi-industrial jam (50% of fruit, referred to as H2). Some variations included the addition of natural lime juice. These formulations did not include pectin. Measurements for the homemade recipe jams were converted to mass or volume using an analytical balance and graduate beaker. The jam was prepared using a Continental® domestic stove with a medium-sized burner, an 18/8 stainless steel pan (240 mm diameter and triple bottom), and a spoon with a length of 10 cm and a 23 cm cable. Defrosted strawberries were placed in the pan with the other ingredients, but different individuals involved in our laboratory routine interpreted the recipe based on their own experience, determining the time to add the ingredients, the power of the stove burner, the mixing frequency, the addition or omission of lemon juice, and the desired final consistency. As a result, 9 different homemade jams were prepared, following a given procedure but processed in different ways by each individual.

<table>
<thead>
<tr>
<th>Table 1: Formulations for homemade (H1 and H2), pilot plant (P1 and P2) and industrial (I1 and I2) jams.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredient</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Strawberry</td>
</tr>
<tr>
<td>Sucrose</td>
</tr>
<tr>
<td>Acid Lime juice</td>
</tr>
<tr>
<td>Concentrated acid lime juice</td>
</tr>
<tr>
<td>Citric Acid*</td>
</tr>
<tr>
<td>Pectin</td>
</tr>
<tr>
<td>Water Added**</td>
</tr>
<tr>
<td>Processed under vacuum</td>
</tr>
</tbody>
</table>

**Source:** author

Figure 1: Total time of process and use of burner power for different homemade jam processes. T_lbp (time using low burner power), T_hbp (time using high burner power), and T_t (total cooking time)

**Source:** author

2.4 Yield Calculation

The yield (%) of each process was calculated using Equation 1, which takes into account the mass (kg) at the beginning of the concentration process (m1) and the mass (kg) of the final product (mf).
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\[ \text{Yield (\%)} = \frac{m_f}{m_i} \times 100\% \quad \text{Equation (1)} \]

2.5 Mass Balance

The mass balance (Equations 2 and 3) was performed by considering the soluble solids of the ingredients: strawberry (x_{st}), lime juice (x_{Lj}), and sugar (considered as 1.0). The mass of strawberry (St), lime juice (Lj), and sugar (Sug) in the formulation, as well as the final Brix of the jam (Bf), were also taken into account. It is important to note that this calculation does not consider losses during the concentration process.

\[ m_i = (St + Lj + Sug) \quad \text{Equation (2)} \]
\[ m_f = (St \times St + Lj \times Lj + Sug \times 1,0)/B_f \quad \text{Equation (3)} \]

2.6 Strawberry pré – processing

2.6.1 Trimming and Washing Water

The quantification of strawberry washing water was conducted using two methods: running water and immersion, with each method performed in triplicate. Quantification using running water involved measuring the flow of tap water using a graduated bucket and a timer to determine the volume used. Flow variations were simulated to represent different operating conditions, including more conscious operations and those with higher waste. For the immersion method, 1 kg of strawberries was weighed, and the minimum amount of water required to move the fruits in the container was added. Water consumption data for industrial processes were provided by the industry.

The inedible parts of the strawberries, such as rot and leaves, were manually removed using a knife, washed, and weighed. Based on industry data, an average loss of 15% in relation to the raw material was considered.

2.6.2 Thermal Energy for Concentration

The thermal energy required for the concentration process was calculated considering the energy obtained from liquefied petroleum gas (LPG) for homemade jam and steam for semi-industrial and industrial jams.

Homemade jams were prepared using a stove with different burner powers and process times. The burner powers considered were 0.8 kW and 1.7 kW for minimum and maximum power, respectively, as specified in the stove supplier manual.

The calculations were performed using Equation 4 (Fellows, 2018) based on mass and energy balance, taking into account the mass (kg) at the beginning of the concentration process \(m_i\), the mass (kg) of the final product \(m_f\), and the mass (kg) of evaporated water \(w_{Aev}\). The fraction of soluble solids at the beginning \(x_i\) and in the final jam \(x_f\) inside the evaporator was also considered. The amount of energy in kcal \(Q_t\) required to evaporate water was determined using Equations 5 and 6. Equation 5 represents the sum of the sensible heat \(Q_s\) required to reach the boiling temperature and the latent heat \(Q_{\gamma v}\) of vaporization necessary to evaporate the water in the jam. \(C_p\) (kcal kg\(^{-1}\) °C\(^{-1}\)) represents the specific heat of water, and \(y_v\) (kcal kg\(^{-1}\)) represents the latent heat of vaporization of water. The thermal properties of water used in the calculations were based on values reported by Alvarado (2016) and Hayes (1987).

\[ w_{ev} = m_i(1 - x_i) - m_f(1 - x_f) \quad \text{Equation (4)} \]
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\[ Q_t = Q_s + Q_y \]  \\
\[ Q_t = m_i C_p (T_{ev} - T_i) + w_{ev} y_v \]

Equation (5)  \\
Equation (6)

2.7 Analysis

2.7.1 Physicochemical Characteristics

The soluble solids analysis, corrected for temperature and acidity, expressed as °Brix, was measured using an automatic refractometer (Reichert Technologies r²i300). The acidity was determined by the titrimetric method using a pH meter (Digimed DM – 20). The pH of the samples was also measured using the same pH meter (IAL, 2008).

2.7.2 Extraction of Anthocyanins

The samples (strawberries and jams) were homogenized in a mortar, weighed, and mixed in tubes protected from light using 50% methanol. They were then subjected to agitation in an AP 56 Phoenix tube shaker for 1 minute and kept on an orbital shaker (Tecnal) for 1 hour. Afterward, the samples were centrifuged at 1500 g for 10 minutes using a Damon centrifuge - IEC Division. The supernatant was filtered using qualitative filter paper. Each sample was processed in triplicate for process evaluation and in duplicate for storage evaluation.

The sample-to-solvent ratio ranged from 1:5 to 4:5 in order to maintain the spectrum absorbance reading in the anthocyanin analysis between 0.2 and 1.0 AU.

2.7.3 Total Monometric Anthocyanins (TMA)

The monomeric anthocyanins (TMA) were quantified using the pH differential method according to AOAC (2016) using a spectrophotometer (Beckman DU-70, Germany). Methanol extracts were diluted in buffers at pH 1 (0.025 M potassium chloride) and pH 4.5 (0.4 M sodium acetate). Absorptions were measured at 520 nm and 700 nm. TMA in strawberries was calculated as equivalents of Pg-3-gluc with a molar extinction coefficient (ε) of 15,600 according to Tonutare, Moor, and Szajdak (2014), and a molecular weight (MW) of 433.2 g/mol. The results were reported as mg anthocyanin per gram of soluble solids of strawberries or jams (mg pg-3-gluc/g sst).

2.7.4 Ascorbic Acid

The ascorbic acid content was evaluated according to method 967.21 in AOAC (2016), modified by Benassi and Antunes (1988). This method is based on the reduction of the 6-dicloindophenol-sodium indicator (DCFI) by ascorbic acid. The results were expressed in mg ascorbic acid per soluble fruit solids (strawberries, acid lime, or the combined amount present in the jams).
2.8 Quality Process Indicators

2.8.1 Color Change

Color measurements (triplicates) of raw strawberry mixtures and jams were conducted using a Hunter Lab LabScan XE (Hunter Associates Laboratory, Reston, VA, USA) based on the CIE Lab* system with illuminant D65 and 10° observers. For the measurement reading, samples were spread in a petri dish, keeping the surface height straight and uniform. The colorimeter was wrapped with PVC film and calibrated after each film change. Total difference (ΔE) was calculated according to Patras et al. (2011), considering the difference between the color of the jam and the color of the homogenized strawberry. Individual values of L*, a*, and b* were evaluated based on their variation during the processing and storage of the industrial and homemade jams.

2.8.2 Total Bioactive Losses during Processing and Storage

The concentration of anthocyanins and ascorbic acid in the jams was expressed according to Equation 7:

\[ L = \left( \frac{C_f}{C_0} \right) \times 100\% \]  

Equation (7)

\( L \) represents the loss (%), \( C_f \) is the concentration of the identified component in the jams after processing or storage (mg of anthocyanin or mg of ascorbic acid per gram of strawberry soluble solids), and \( C_0 \) is the concentration of the component before processing (mg of anthocyanin or mg of ascorbic acid per gram of strawberry soluble solids). When lemon juice was added to the formulation, it was taken into account, and \( C_0 \) was calculated as mg of ascorbic acid per gram of soluble solids of the fruits (strawberry and lemon juice).

2.8.3 Degradation Kinetics of Industrial Jam

Anthocyanin and ascorbic acid degradation was monitored for up to 98 days. Since the industrial jams were purchased with a certain storage time (14 and 62 days) at 25 °C, the reaction speed, k value (days\(^{-1}\)), for anthocyanins, ascorbic acid, and color parameters was estimated, considering the same degradation kinetics as the semi-industrial jams.

Significant differences (\( p < 0.05 \)) between means were determined through analysis of variance (ANOVA), followed by Tukey's test. A t-test was used to compare two samples. All statistical analyses were performed using RStudio 1.1.463 and Sisvar software.

3 RESULTS AND DISCUSSIONS

3.1 Physicochemical Characteristics

3.1.1 Raw Material

Table 2 presents the physicochemical composition of strawberries, including some bioactive compounds. The M2 sample had a lower soluble solids content than the M1 mix. The total monomeric anthocyanins (TMA) content in M1 and M2 were significantly different (\( p<0.05 \)), with M2 having a higher content of anthocyanins. However, the content of ascorbic acid was not significantly different (\( p<0.05 \)) between the two samples. To standardize the
results, they were also expressed in relation to the soluble solids of the strawberries, maintaining the same trend.

**Table 2: Physicochemical characteristics, ascorbic acid and anthocyanin content of raw materials of strawberry jams.**

<table>
<thead>
<tr>
<th>Raw material</th>
<th>°Brix</th>
<th>pH</th>
<th>Acidity</th>
<th>AA mg/100g</th>
<th>AA mg/g sst</th>
<th>TMA mg/100g*</th>
<th>TMA mg/g sst*</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>8.30±0.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.51±0.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.88±0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>53.77±2.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.48</td>
<td>38.61±0.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.65</td>
</tr>
<tr>
<td>M2</td>
<td>6.80±0.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.49±0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.17±0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>42.41±5.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.21</td>
<td>40.17±0.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.88</td>
</tr>
</tbody>
</table>

**Source:** author

Different letters in the same column differ from each other (p < 0.05).

AA: Ascorbic Acid, expressed by 100g of sample, and by g of total soluble solids.

TMA: Total monomeric anthocyanins, expressed by 100g of sample, and by g of total soluble solids.

M1: Strawberry mixture of varieties Camino Real, Benícia, San Andreas and Senga Sengana.

M2: Variety Camino Real.

These results are consistent with findings from other authors. Pineli et al. (2011) found that the content of ascorbic acid and soluble solids in Oso Grande and Camino Real varieties varied from 23.1 to 52.8 mg/100g and 5.0 to 7.9 °Brix, respectively, at three stages of harvest maturity. Mazur et al. (2014) reported total monomeric anthocyanin (TMA) ranging from 36.9 to 53.9 mg/100g of strawberry for three different varieties at different stages of ripeness, with soluble solids ranging from 8.0% to 10.7%. Martinsen, Aaby, and Skrede (2020) found an average concentration of 66.1 mg/100g of TMA and 50.1 mg/100g of AA for the Senga Sengana variety with total soluble solids of 10 °Brix.

### 3.1.2 Jam

According to Table 3, a standardized process led to better control of the final Brix, as observed in the industrial or semi-industrial jams (no statistical difference, p<0.05), which ranged from 57.8 (P2) to 59.5 (I1). Non-standardized homemade jams resulted in a bigger difference between less and more concentrated jams in both H1 and H2 series (Table 3).

**Tabela 3: Physicochemical characteristics of jams.**

<table>
<thead>
<tr>
<th>Process*</th>
<th>Acidity (%)</th>
<th>°Brix (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1_1</td>
<td>0.83±0.01&lt;sup&gt;c,f&lt;/sup&gt;</td>
<td>45.2±0.8&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3.27±0.04&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>H1_2</td>
<td>0.93±0.02&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>50.7±1.7&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
<td>3.31±0.03&lt;sup&gt;b,c,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>H1_3</td>
<td>1.05±0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>50.0±0.5&lt;sup&gt;k,e&lt;/sup&gt;</td>
<td>3.28±0.02&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>H1_4</td>
<td>0.84±0.01&lt;sup&gt;c,f&lt;/sup&gt;</td>
<td>54.9±2.2&lt;sup&gt;b,c,d&lt;/sup&gt;</td>
<td>3.50±0.08&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>H1_5</td>
<td>1.19±0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>58.5±0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.37±0.07&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
</tr>
<tr>
<td>H2_1</td>
<td>0.68±0.05&lt;sup&gt;b&lt;/sup&gt;</td>
<td>56.4±0.6&lt;sup&gt;k,e&lt;/sup&gt;</td>
<td>3.36±0.03&lt;sup&gt;b,c,d&lt;/sup&gt;</td>
</tr>
<tr>
<td>H2_2</td>
<td>0.77±0.05&lt;sup&gt;c,g&lt;/sup&gt;</td>
<td>70.0±4.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.47±0.06&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>H2_3</td>
<td>0.59±0.02&lt;sup&gt;i&lt;/sup&gt;</td>
<td>70.6±1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.45±0.02&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>H2_4</td>
<td>0.88±0.00&lt;sup&gt;d,e&lt;/sup&gt;</td>
<td>70.8±0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.30±0.08&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>P1</td>
<td>0.99±0.04&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>59.3±1.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.23±0.03&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>P2</td>
<td>0.78±0.01&lt;sup&gt;c,g&lt;/sup&gt;</td>
<td>57.8±4.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.15±0.07&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>I1</td>
<td>0.74±0.02&lt;sup&gt;b,h&lt;/sup&gt;</td>
<td>59.5±0.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.21±0.05&lt;sup&gt;d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td>I2</td>
<td>0.82±0.02&lt;sup&gt;c,f&lt;/sup&gt;</td>
<td>59.0±1.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.32±0.06&lt;sup&gt;b,c,d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Source:** author


*Being H1_4 and H2_3 processed without lemon juice.

*P1, P2 and I2 acidified with citric acid.

Different letters in the same column differ from each other (p < 0.05).
The initial sugar content in the H2 series contributed to a general greater concentration of soluble solids in the final product, but even within this group, the Brix variation had statistical significance (p<0.05). Homemade jams in the H1 series varied from 45.2 to 58.5 °Brix, while the H2 series varied from 56.4 to 70.8.

The heating exposure time contributed to a greater amount of water loss, increasing the concentration of soluble solids. Jams processed faster (H1_1, H2_1) presented lower final °Brix. The effect of burner power can be observed by the difference between samples H2_1 and H2_2, which were made at the same time but using different burner powers. For the higher burner power (H2_2), the final °Brix was higher.

3.2 Process Indicators

3.2.1 Color

Values of Lab* and ΔE for homemade and semi-industrial jams, just after processing, can be observed in figure 2. In general, although homemade and semi-industrial jams present variations in the parameters L*, a*, and b*, homemade jams showed the greatest dispersion (14.02 to 34.49, 35.95 to 50.85, and 23.93 to 56.54, for L*, a*, and b*, respectively). According to Patras et al. (2011), the total color difference (ΔE) indicates the difference between samples and a control. The samples can be very distinct when ΔE > 3, just distinct when 1.5 < ΔE < 3, or they have a little difference when ΔE < 1.5 (Adekunte et al., 2010). The homemade sample H2_4 was processed for the longest time, and its color parameters differed from the other samples, especially in terms of ΔE (30.14 ± 4.42 after processing), indicating a more severe processing.

![Figure 2: Color parameters L*a*b* and ΔE of the homemade and semi-industrial jams just after processing. Percentage of strawberrysugar: H1 64:34; H2 49:49. Being H1_4 and H2_3 processed without lemon juice addition. Being L* = luminosity; a* (+a* = r).](image)

Source: author

Total color parameters for industrial and semi-industrial jams can be seen in figure 3. Similar to homemade jams, the processing methods of semi-industrial and industrial jams (P1, P2) resulted in a ΔE>3, indicating differentiation from fresh strawberry.

During the shelf life, a decrease in the values of L*, a*, and b* can be observed, leading to an increase in the Delta value. Color changes can occur due to the formation of brown
polymers resulting from the transformation of anthocyanins and the degradation of vitamin C and sugar (Mazur, 2012).

However, the mixture also contains sugar and other compounds that contribute to the emergence of other browning compounds. Sucrose can undergo inversion, increasing.

The glucose and fructose content in the jam under acidic and heat conditions. These inverted sugars can react with amino acids in the fruit and participate in the Maillard reaction, which contributes to browning (Abers and Wrolstad, 1979).

Data on anthocyanin and ascorbic acid losses are presented in figure 4. The jams H1_1 to H1_5 had a similar proportion of strawberries (64%). Despite the variation in the amount of acid lime juice, all H1 jams showed similarity (p> 5%) in terms of anthocyanin content. However, concerning ascorbic acid content, only H1_2 obtained a lower value, which may be attributed to a more intense disintegration of the fruits in this process.

![Figure 3: Color parameters L, *a, *b and ΔE of industrial jams method during storage. Source: author](image-url)
Comparative Analysis of Industrial and Homemade Strawberry Jam Processing: Quality, Degradation, and Energy Consumption

Figure 4: Anthocyanin and Ascorbic acid losses in process and storage for 14 days for semi industrial and homemade method.

Source: author

*Percentage of strawberry: sugar: H1 64:34; H2 49:49; P1: 50:50; P2: 49:49; I1: 50:48; I2: 50:49. Being H1_4 and H2_3 processed without lemon juice addition. P1 and P2 acidified with citric acid. Anthocyanin loss in H2_1 was 0%.

Regarding the H2 group, which had a consistent proportion of 50% strawberries, H2_1 exhibited higher anthocyanin and ascorbic acid content compared to the other jams in the group, possibly due to a faster process and a lower final Brix value (56.4). The other jams in this group reached approximately 70 °Brix and had a lower anthocyanin content, indicating the effect of heat degradation.

Jams exposed to longer periods of heat, such as H1_5 (49 minutes) and H2_4 (60 minutes), experienced the highest anthocyanin and ascorbic acid losses after 14 days of storage. This suggests that the duration of heat exposure during processing can influence degradation during storage. This factor can be observed for P1, which was obtained through a vacuum concentration process at 85 °C.

3.2.2 Degradation Kinetic

3.2.2.1 Industrial and semi-industrial jams during storage

In terms of degradation kinetics, figure 5 presents the linear regression analysis for determining the reaction rate (k) of total anthocyanins (pg-3-glu/tss strawberry) and ascorbic acid (mg/tss strawberry) during storage, considering both industrial and semi-industrial jams. For anthocyanins, R2 was 82.76%, and the rate constant (k) was calculated as 0.0153 day⁻¹ (D25 °C = 150.52 days). De Moura et al. (2012) reported a k value of 0.0125 day⁻¹ (D25 °C = 184.24 days) for classic blackberry jam and 0.0143 day⁻¹ (D25 °C = 161.04 days) for low sugar blackberry jam, which are comparable to the values obtained in this study.

Regarding ascorbic acid, the rate constant (k) was 0.0164 day⁻¹ (D25 °C = 140.42 days), and R2 was 91.82%. Patras (2011) found a k value of 0.0454 day⁻¹ (D15 °C = 50 days) for ascorbic acid in strawberry jam. However for low water content products such as concentrated grapefruit fruit at 62.5 °Brix, D = 4.3 days (Saguy, Kopelpan, and Mizrahi, 1978), and for dried guava paste, the k value was 0.391 day⁻¹ at 30 °C (D30 °C = 6 days) (Uddin et al., 2002). These
values indicate that the degradation kinetics of ascorbic acid are more complex in low water content products compared to the findings of this study.

![Figure 5](image)

**Figure 5:** Linearized relationship for determination of the parameter k for total anthocyanins (pg-3-glu/tss strawberry) and for ascorbic acid (mg/tss strawberry) during storage for industrial and semi industrial jams. tss means total soluble solids.

Source: author

In comparison to homemade jam, industrial jam 12, which had been stored for 62 days, exhibited lower levels of anthocyanins and ascorbic acid. These degradations are likely attributed to the storage conditions rather than the manufacturing process. It would be necessary to evaluate the kinetics of the homemade method to compare the degradation rates of quality parameters. However, the color parameters, concentration of total monomeric anthocyanin, and ascorbic acid degradation did not follow a first-order kinetic model. This discrepancy could be attributed to significant variations in the homemade process, leading to results where the concentration did not depend solely on time and temperature. These findings indicate non-standardized jams with unpredictable concentrations of analyzed micronutrients and color degradation. It demonstrates that these parameters are not solely dependent on time/temperature but are influenced by other factors.

### 3.3 Strawberry Pré-Processing

The flow rates used for washing strawberries in running water were 1.35, 1.93, and 4.06 L/h, with water consumption ranging from 9.5 to 20 liters per 1 kg of strawberries washed. In contrast, strawberries washed by immersion consumed an average of 1.63 ± 0.15 liters of water per 1 kg of strawberries, which is similar to the water consumption in the industry, approximately 1.5 kg of water per 1 kg of strawberries (according to industry data).

Based on experimental data, the percentage of losses in relation to the inedible parts of the fruit was, on average, 11.61% ± 1.69% for intercrop strawberries and 7.86% ± 1.05% for harvest strawberries, indicating better quality in fruits harvested during the main season. However, it should be noted that homemade strawberries come from selected raw materials specific to the retail market, whereas the industry reports a disposal rate of approximately 15%, with most of this raw material being unsuitable for the retail market due to color, size, and other imperfections.

The type of production also influences the amount of waste. In Denmark, it was estimated that losses in field production reached 15%, 5% in tunnels, and 2% to 3% in greenhouses (Borun et al., 2018). The results obtained in this study, both for industrial and homemade jams, fall within the maximum 15% range.
According to Cárdenas (2017), sources of residues in the industry may include strawberries that have not undergone pre-selection, as well as the disposal of pedicles and cups. The amount of strawberry residues, based on data from a company in Peru, is approximately 150 kg per ton, which is equivalent to 15%.

The yield for industrial and pilot plant jams was homogeneous and above 90%, while for homemade jams, it ranged from 67.2% to 78.9%, except for H1_1 and H2_1, which reached 87.0% and 94.48%, respectively. However, these jams exhibited much lower final Brix values compared to the other homemade samples.

3.3.1 Thermal Energy Required in the Concentration Process

The homemade formulations underwent different heating times and burner power, resulting in jellies that consumed varying amounts of energy. Energy consumption for the evaporation of 1 kg of water ranged from 1278 to 2999 kcal for household processes. These values surpassed the average industrial values by 80% to 323%. There seems to be a lack of clear understanding among the general population regarding the energy required to produce jam, whether homemade or industrially. While it might be assumed that producing larger quantities of jam would require more energy compared to homemade preparations, an analysis of the energy consumed per kg of jam produced reveals that the industrial process is much more economical (Table 4).

The use of vacuum in the concentration process is a technology employed in several industrial processes and can be considered a more sophisticated method compared to atmospheric pressure. It is observed that the energy required for water evaporation decreases when the process temperature (inside the vessel) is lower, which is achievable through the use of vacuum.

The energy required for the process includes both sensible heat and latent heat. Operating under vacuum at lower boiling temperatures reduces sensible heat. However, the latent heat remains relatively unchanged, and as it is the main contributor to energy consumption in the process, the overall energy consumption does not decrease proportionally. The advantage of this operation lies in the fact that chemical changes are minimized as degradation reactions occur to a lesser extent at lower temperatures. From an operational perspective, a vacuum pan is a more expensive piece of equipment but requires less maintenance.

<table>
<thead>
<tr>
<th>Table 4: Process conditions for homemade jams</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_{cm} ) (min:s)</td>
</tr>
<tr>
<td>-----------------------</td>
</tr>
<tr>
<td>H1_1</td>
</tr>
<tr>
<td>H1_2</td>
</tr>
<tr>
<td>H1_3</td>
</tr>
<tr>
<td>H1_4</td>
</tr>
<tr>
<td>H1_5</td>
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</tr>
<tr>
<td>P2</td>
</tr>
<tr>
<td>I1</td>
</tr>
<tr>
<td>I2</td>
</tr>
</tbody>
</table>

Source: Author
Comparative Analysis of Industrial and Homemade Strawberry Jam Processing: Quality, Degradation, and Energy Consumption

tcm: cooking time at minimum power (0.8W),
tcf: cooking time at full power (1.7 W),
tf: time of cooking = tpb+tpa, (min:s),
Bf: jam final Brix,
mf: mass of jam (kg),
Wev: evaporated water (kg),
Qt: calculated total energy (kcal).

4 CONCLUSÃO

The overall conclusion of the tests conducted on industrial, semi-industrial, and homemade jams is as follows:

Color Parameters: The color parameters, including Lab* values and ΔE, showed changes during processing and storage. Both industrial and semi-industrial jams exhibited color differentiation from fresh strawberries, indicating color degradation over time. Homemade jams exhibited larger manufacturing variations, leading to non-standardized color parameters.

Anthocyanin and Ascorbic Acid Losses: The content of anthocyanins and ascorbic acid in the jams varied based on processing methods, strawberry proportion, and heat exposure. Longer heat exposure during processing and storage led to higher losses of anthocyanins and ascorbic acid. The degradation kinetics of these compounds did not strictly follow a first-order kinetic, suggesting the influence of multiple factors.

Strawberry Pre-processing: The pre-processing steps, including washing and waste management, varied between industrial and homemade production. Water consumption for washing strawberries differed based on the method employed, and homemade strawberries were sourced from the retail market, leading to selected raw materials. Industrial production reported a higher disposal rate of strawberry residues.

Yield and Energy Consumption: The yield of industrial and pilot plant jams was consistently above 90%, while homemade jams showed variations in yield. Energy consumption for water evaporation during the concentration process was higher in homemade processes compared to industrial processes. The industrial process proved to be more energy-efficient when considering energy consumed per kilogram of jam produced.

Vacuum Processing: Vacuum processing, used in industrial processes, offered advantages such as lower process temperatures, reduced sensible heat, and minimized chemical changes and degradation reactions. However, vacuum processing requires more expensive and maintenance-intensive equipment.

The tests revealed variations in color parameters, losses of anthocyanins and ascorbic acid, differences in pre-processing methods, yield, and energy consumption between industrial, semi-industrial, and homemade jams. The use of vacuum processing in industrial settings demonstrated potential benefits in terms of energy efficiency and product quality.

These findings highlight the importance of process control, standardization, raw material considerations, energy efficiency when developing and manufacturing various food products.

These controls, even in small productions, can guarantee the quality of products in a satisfactory way for consumers in general. In addition to guaranteeing less waste in production.

REFERENCES


DAMODARAN, Srinivasan; PARKIN, Kirk L. Química de alimentos de Fennema. Artmed Editora, 4ª ed. 2010.


Duch.) fruits and their suitability for jam production as a stable product at different storage temperatures. Food chemistry, 146, 412-422.


