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ORIGINAL ARTICLE

Sugarcane (*Saccharum officinarum*) bagasse as a source of fiber and fat replacer in ice creams: chemical, microbiological, and sensory evaluation

Bagaço de cana-de-açúcar (Saccharum officinarum) como fonte de fibras e substituto de gordura em gelados: avaliação química, microbiológica e sensorial

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Abstract

Agricultural by-products are relevant sources of valuable bioactive compounds, such as fiber, which its regular ingestion is associated with health benefits. This study evaluated the chemical, microbiological, and sensory properties of ice cream using the sugarcane bagasse as a partial fat replacer and fiber-enrichment component. Three ice cream formulations containing 15% (T1); 20% (T2) and 25% (T3) of sieved dried bagasse fiber were produced and compared against a control ice cream (C) without including the by-product. Fat content reduction was 53.40%, 78.88% and 81.99%, respectively; and, the total dietary fiber values increased 14.2%, 19.0% and 24.3%, respectively. Microbiological parameters of all ice cream formulations complied with the requirements established in the Ecuadorian standard for ice creams - NTE INEN 706:2013 and the limits for the mold and yeast count included in the Argentine Food Code. Compared with the control sample (C), formulation T1 did not show a significant statistical difference ($p > 0.05$) for four out of the five sensory parameters assessed (appearance, texture, flavor, and general acceptance, except taste) using a 9-point structured hedonic scale. The bagasse fiber resulted in a promising food ingredient suitable for reducing fat content and increasing fiber value.

Keywords: By-products; Fat replacer; Fiber powder; Low-fat ice cream; Probiotic viability; Sensory acceptance; Sugarcane bagasse; Waste revalorization.

Resumo

Os subprodutos agrícolas são fontes relevantes de compostos bioativos valiosos, como a fibra, cuja ingestão regular está associada a benefícios à saúde. Este estudo avaliou as propriedades químicas, microbiológicas e sensoriais de sorvetes utilizando o bagaço de cana como substituto parcial de gordura e componente enriquecido com fibras. Três formulações de sorvete contendo 15% (T1), 20% (T2) e 25% (T3) de fibra de bagaço desidratada peneirada foram produzidas e comparadas com um sorvete controle (C) sem incluir o subproduto. A redução do teor de gordura foi de 53,40%, 78,88% e 81,99%, respectivamente; os valores de fibra alimentar total aumentaram em 14,2%, 19,0% e 24,3%, respectivamente. Os parâmetros microbiológicos de todas as formulações de sorvetes atenderam aos requisitos estabelecidos na norma equatoriana para sorvetes - NTE INEN 706:2013 e os limites para a contagem de bolores e leveduras do Código Alimentar Argentino. Comparada com a amostra controle (C), a formulação T1 não apresentou diferença estatisticamente significativa (p > 0,05) para quatro dos cinco parâmetros sensoriais avaliados (aparência, textura, sabor e aceitação geral, exceto sabor) usando uma escala hedônica de 9 pontos. A fibra do bagaço resultou em um ingrediente alimentar promissor, adequado para reduzir o teor de gordura e aumentar o valor da fibra.

Palavras-chave: Subprodutos; Substituto de gordura; Fibra em pó; Sorvete com baixo teor de gordura; Viabilidade probiótica; Aceitação sensorial; Bagaço da cana-de-açúcar; Revalorização de resíduos.

Highlights

- The sugarcane bagasse was dried, powdered, and incorporated into ice creams
- Sugarcane bagasse is a potential source of fiber and partial fat replacer in ice cream
- 15% of sugarcane bagasse as an ice cream ingredient did not significantly alter the sensory properties except for the taste parameter

1 Introduction

Nowadays, there is an increased pattern of awareness of food consumers towards demanding healthier products. Several agricultural by-products have been attracting the attention of the food industry for being a source of valuable compounds that could be incorporated into the development of functional foods. Sugarcane is one of the most cultivated crops in tropical countries with an annual world production of 1.91 billion tonnes. Sugarcane bagasse is one of the principal by-products obtained from the manufacturing of sugar (Dotaniya et al., 2016). From every 10 tonnes of sugarcane used in the juice extraction, 3 tonnes of solid by-products (bagasse) are generated (Yadav et al., 2015). The most likely destinations for a large section of these by-products are to be incinerated as a source of energy and disposed of in landfills, which contributes to environmental pollution. Meanwhile, a small amount might be destined to produce bioethanol fuel (Verma et al., 2012).

Sugarcane bagasse is a rich source of insoluble fiber such as cellulose (50%), hemicellulose (25%), and lignin (25%) (Balaji et al., 2014). Insoluble fiber is a fraction of the total dietary fiber which, when ingested, does not form gel due to its water insolubility, resistance to fermentation (Lattimer & Haub, 2010), or ferments to a restricted degree in the colon (Ötles & Ozgoz, 2014). The role of fiber in a healthy digestion process is influenced by decreasing the intestinal transit time and increasing the bulking of stool (Skiba et al., 2019). Another potential suggested mechanism is the fermentation of fiber into butyrate produced by gut microbiota, butyrate is a short-chain fatty acid that exhibits essential homeostatic properties thus preventing/inhibiting carcinogenesis (Gonçalves & Martel, 2013; Bultman, 2014). Benefits associated with the ingestion of fiber involve reducing LDL (low-density lipoproteins) cholesterol levels and insulin levels and decreasing postprandial blood glucose (Lunn & Buttriss, 2007). Moreover, evidence indicates that fiber induces a chemoprotective effect on cancer propagation and metastasis (Papandreou et al., 2015). Therefore, it is important to consume it. According to the Food and Drug Administration (FDA), the recommended daily intake of fiber should be around 25 g (Anjali & Vijayaraj, 2020).

Ice cream is one of the most consumed foods with a yearly worldwide market revenue of US$ 73.8 billion, its massive popularity may be attributed to factors such as a high diversity of ingredients, multiple presentations, shapes, and flavors. Despite this high demand, traditionally, ice creams have been regarded as non or barely-nutritive tasty desserts (Goff & Hartel, 2013). Nowadays there is a growing interest in the development of ice creams as a vehicle of health-promoting compounds, such as probiotics, prebiotics, dietary fiber, natural antioxidants, and fatty acids (Soukoulis et al., 2014).

The aim of this study was to develop a fat-reduced and high-fiber content strawberry ice cream using the bagasse fibers from the sugarcane by-products as a source of fiber enrichment and partial replacement of fat. The chemical, microbiological and sensory characteristics of the ice creams were evaluated.

2 Materials and methods

2.1 Sugarcane bagasse fiber (SBF)

Prior to their use, the craft stainless steel sugarcane mill roller as well as the sugarcanes were washed, disinfected using a 5000 ppm sodium hypochlorite solution, and thoroughly rinsed with potable water. After being crushed, the bagasse was collected and placed in high-density polyethylene (HDPE) buckets with their respective hermetic lids. Buckets were kept under refrigeration at 4°C. Using a convection oven at 55 °C, the bagasse was dried for approximately 12 h until reached constant weight. Then, the particle size of the SBF was reduced using a lab-scale roller mill. The bagasse-powder alike was passed through a 40-mesh sieve. The sieved powder was autoclaved at 121 °C for 20 min for microbial and enzymatic inactivation, after cooling down it was placed in HDPE bags then vacuum-sealed and kept in refrigeration at 4 °C until use.

2.2 Ice cream development

Four treatments of ice cream were developed (Table 1). Three of them (T1, T2, and T3) contained different percentages of SBF (15%, 20% and 25%) which partially replaced the cream, as the source of fat. The last one (C) was used as a control excluding the sugarcane by-product.

Table 1. Ice cream formulations.

Component	Treatment			
	T1	T2	T3	C
SBF (%)	15	20	25	0
Sugar (%)	5	5	5	5
Strawberry fruit concentrate (%)	6	6	6	6
Evaporated milk (%)	60	60	60	60
Cream pasteurized milk (%)	13.3	8.3	3.3	28.3
Guar gum (%)	0.3	0.3	0.3	0.3
Xanthan gum (%)	0.4	0.4	0.4	0.4
Total (%)	100	100	100	100

T1, T2, and T3: treatments of ice cream containing different percentages of sugarcane bagasse fiber (15%, 20% and 25%, respectively). C: control excluding the sugarcane by-product.

2.3 Chemical and microbiological analyses

Chemical and microbiological reference criteria were taken from the Ecuadorian standard NTE INEN 706:2013 (Servicio Ecuatoriano de Normalización, 2013), which lists the requisites for ice cream and ice cream mixtures. The Argentine Food Code (Argentina, 2021) provided the criteria limits for the counts of mold and yeast.

Total Dietary Fiber (TDF) (AOAC 991.43), total fat (AOAC 995.19), and Total Solids (TS) (AOAC 941.08) contents were determined following the procedures described by AOAC (Association of Official Agricultural Chemists, 2012) methods.

The microbiological assays and the procedures were: aerobic plate count (AOAC 966.23), total coliforms count (AOAC 991.14), *Escherichia coli* count (AOAC 991.14), enumeration of *Salmonella* spp. (AOAC 967.26), enumeration of *Listeria monocytogenes* (AOAC 2013.10), enumeration of *Staphylococcus aureus* (AOAC 2003.07) and mold and yeast counts (AOAC 997.02). All essays were performed in triplicate.

2.4 Sensory evaluation

Thirty untrained panelists, who are regular consumers of ice cream and students from the last semester of the Agro-industrial Engineering department, used a 9-level hedonic rating scale (Lawless & Heymann, 2013) for the assessment of appearance, texture, flavor, taste, and general acceptance. The scale ranged from the highest (9 – Like it extremely) to the lowest (1 – Dislike it extremely). Briefly, 40 g of each sample identified with a random three-digit code were served at -10 °C in plastic cups and given to the panelists. Prior to the evaluation, the ice creams remained under freezing at -18 °C.

2.5 Statistical analysis

Data were evaluated using one-way Analysis of Variance (ANOVA) and Tukey's test at a level of significance of 0.05. Minitab statistical software v. 19.2020.2 was employed to perform the statistical analyses. All assays were performed in triplicate.

3 Results and discussion

3.1 Chemical results

All ice cream samples containing the SBF showed a notable reduction in fat content compared with the control ice cream (Table 2). The decrease percentage in fat content was 53.40%, 78.88% and 81.99% for T1, T2, and T3, respectively. These results are in partial agreement with the 51% average lipid content reduction reported by Crizel et al. (2014), who used orange fiber, from their peels and bagasse, as a partial replacer of fat in the elaboration of ice creams. Additionally, our results resemble those mentioned by Meneses et al. (2020), who indicated a fat content decrease ranging from 28.49% up to 54.81% for the utilization of dairy by-products instead of whole milk in the production of ice creams.

The ice cream's TDF content (Table 2) displayed a pattern closely similar to the added SBF values in each formulation, this strongly suggests that the TDF content found in the experimental ice creams is due to a considerable extent to the added sugarcane bagasse fiber. Part of our findings is related to those exposed by Barrionuevo et al. (2011), who reported a 12.51% content of total fiber using inulin powder as an ingredient in the elaboration of a blueberry ice cream with prebiotic characteristics.

The TS content (Table 2) of the ice creams varied significantly between formulations with the exceptions of T2 and T3. The TS values of all formulations increased with the addition of bagasse fiber. Partially similar to these results, Akalın et al. (2018) and Erkaya et al. (2012), reported a rising from 34.64% to 37.52% and from 29.31% to 35.20% in the TS content of ice creams elaborated with fibers obtained from different natural sources. It has been reported that an increase in TS content has an overall ice crystal size reduction (Flores & Goff, 1999), the mechanism involved refers that the presence of more total solids reduces the amount of water available for crystallization, therefore, reducing the total quantity of ice formed (Adapa et al., 2000). Ice crystal size is a fundamental factor in the sensory quality of ice creams, as is directly related to providing a creamy texture, as well as shelf-life, as crystals keep constantly growing by recrystallization during storage (Cook & Hartel, 2010).

Table 2. Results of chemical assays.

Component	Treatment			
	T1	T2	T3	C
Total fat (%)	7.04 ± 0.18^{a}	3.19 ± 0.1^{b}	2.72 ± 0.15^{c}	15.11 ± 0.23^{d}
TDF (%)	14.2 ± 0.08^{a}	19.0 ± 0.06^{b}	24.3 ± 0.09^{c}	ND
Total solids (%)	73.62 ± 1.02^{a}	78.42 ± 0.92^{b}	78.87 ± 0.72^{b}	65.04 ± 0.63^{c}

Means of three replicates ± standard deviation. Means with a different letter in the same row denote significant statistical differences (p > 0.05). ND: not determined. T1, T2, and T3: treatments of ice cream containing different percentages of sugarcane bagasse fiber (15%, 20% and 25%, respectively). C: control excluding the sugarcane by-product.

3.2 Microbiological results

The results of the microbiological studies are presented in Table 3. According to the results, the addition of SBF to the formulations did not affect any of the microbiological parameters evaluated. Moreover, it is worth mentioning that all the parameters comply with the requirements of the Ecuadorian standard for ice cream – INEN 706:2013. According to the Argentine Food Code described in the legislation for ice cream, the mold and yeast counts were in compliance. Conformity to food standards, more specifically to microbiological requisites, in dairy-related food products, such as in the case of ice creams, is an essential condition to safeguard consumers' food safety (Wolf-Hall & Nganje, 2017).

Table 3. Microbiological quality of samples.

Parameter	Treatment				Requirement*
	T1	T2	T3	C	
Aerobic plate count [CFU/g]	4.2 x 10^1	4.4 x 10^1	4.5 x 10^1	4.3 x 10^1	< 1.0 x 10^4
Total coliforms count [MPN/g]	3.5 x 10^1	3.8 x 10^1	3.4 x 10^1	3.7 x 10^1	< 1.0 x 10^2
E. coli count [MPN/g]	< 3.0	< 3.0	< 3.0	< 3.0	< 3.0
Salmonella	Absent	Absent	Absent	Absent	Absent
L. monocytogenes	Absent	Absent	Absent	Absent	Absent
S. aureus [CFU/g]	1.0 x 10^1	1.0 x 10^1	1.0 x 10^1	1.0 x 10^1	< 1.0 x 10^2
Molds & yeasts [CFU/g]	10	10	10	10	< 100[&]

*Requisites were taken from the Ecuadorian standard for ice creams – INEN 706:2013 (Servicio Ecuatoriano de Normalización, 2013). [&]Requisite considered from the Argentine Food Code (Argentina, 2021). T1, T2, and T3: treatments of ice cream containing different percentages of sugarcane bagasse fiber (15%, 20% and 25%, respectively). C: control excluding the sugarcane by-product.

3.3 Sensory evaluation

The results of the sensory evaluation are displayed in Table 4. The control (C) was rated as the ice cream with the highest sensory acceptance, closely followed by formulation T1. In terms of appearance, texture, flavor, and general acceptance there are no significant differences ($p > 0.05$) between the control and the ice cream including 15% of bagasse fiber – T1. On the other hand, the experimental formulations composed of 20% and 25% of SBF, T2, and T3, respectively, had considerably lower scores in the 5 attributes compared to the control. In these two specific samples, the panelists informed a distasteful grainy and lumpy sensation that influenced the overall perception. Our results are in agreement with the findings reported previously (Dervisoglu & Yazici, 2006; Siçramaz et al., 2016).

Table 4. Sensory evaluation results (9-level hedonic rating scale).

Sensory parameter	Treatment			
	T1	T2	T3	C
Appearance	8.2 ± 0.72^{a}	7.4 ± 1.32^{bc}	7.1 ± 1.55^{c}	8.0 ± 0.90^{a}
Taste	7.56 ± 0.87^{b}	5.8 ± 1.09^{c}	5.9 ± 1.49^{c}	8.0 ± 0.84^{a}
Texture	8.1 ± 0.87^{a}	6.2 ± 1.61^{b}	6.1 ± 1.43^{b}	8.0 ± 1.23^{a}
Flavor	8.1 ± 0.79^{a}	7.5 ± 1.40^{b}	7.3 ± 1.44^{b}	8.0 ± 0.71^{a}
General acceptance	8.1 ± 0.81^{a}	7.0 ± 1.34^{b}	6.6 ± 1.29^{c}	8.2 ± 0.76^{a}

Means of three replicates ± standard deviation. Means with a different letter in the same row denote significant statistical differences ($p > 0.05$). T1, T2, and T3: treatments of ice cream containing different percentages of sieved dried bagasse fiber (15%, 20% and 25%, respectively). C: control excluding the sugarcane by-product.

As shown in Figure 1, except for the taste parameter, there is almost no difference between the control ice cream (C) and the experimental formulation T1. It is observed (Figure 1) that the addition of SBF negatively affected the taste and texture parameters, more specifically for the experimental formulations T2 and T3, which substituted the source of fat (milk cream) for 20% and 25%. Previously, it has been declared that the partial substitution of fat by dietary fiber can modify the sensory attributes of ice creams, particularly their textural properties, however, its addition also influences positively other aspects such as improving water holding capacity, avoiding syneresis and improving shelf-life (Akbari et al., 2019).

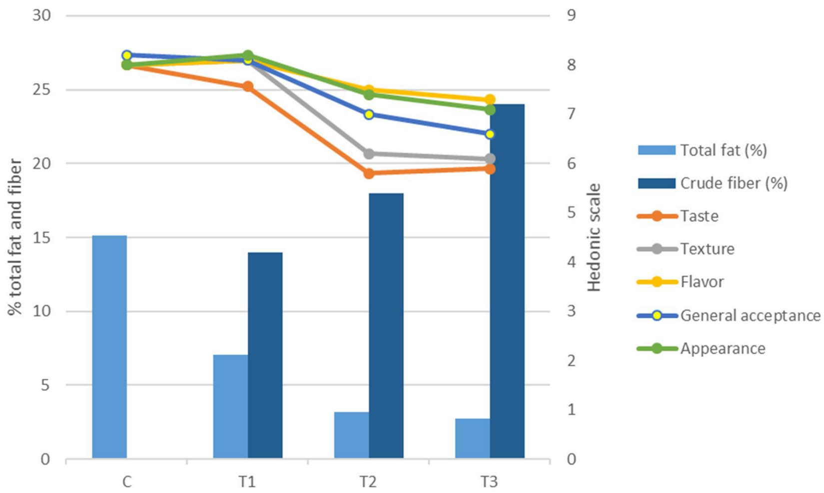

Figure 1. Total fat (%) and TDF fiber (%) *versus* sensory acceptance.

4 Conclusion

The inclusion of bagasse fiber derived from the sugarcane by-products in the ice cream formulations increased its Total Dietary Fiber content. Simultaneously, the fat content of ice creams was notoriously reduced. Both are worthwhile attributes to be considered in the manufacture of healthier foods. Fifteen percent of sugarcane bagasse fiber incorporation did not significantly alter four of the five sensory parameters (appearance, texture, flavor, and general acceptance, excluding taste) assessed in the ice cream. In conclusion, the bagasse fiber may be revalorized incorporating it as a source of fiber and as a partial fat replacer.

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