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Development and Quality Evaluation of Gluten-Free Wafer Sheets Enriched with Strawberry Powder for Use in the Production of Gluten-Free Ice Cream Cones

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RESEARCH ARTICLE

Abstract
This study aimed to develop gluten-free wafer sheets (GFWS) by using strawberry powder (SP) with improved nutritional, technological, and sensory properties for use in gluten-free ice cream cone (GFIC) production. The gluten-free flour mixture (GFFM), comprising corn and rice flour, corn, and potato starch, was enriched with SP at varying ratios (0%, 10%, 20%, and 30%) to accomplish the designated goal. GFWS produced by adding SP was evaluated in terms of physical, chemical, textural, and sensory properties. As the SP substitution level increased, the GFWS's thickness, redness, and ash content increased while its width, brightness, moisture content, and pH decreased. When the amount of SP in the GFFM was increased, the hardness and fracturability of the GFWS showed a reduction. The inclusion of SP in GFWS led to a proportional increase in their nutritional fiber content. Regarding sensory attributes, the GFWS fortified with SP exhibited higher overall acceptability ratings than the control group (without SP). The study's results demonstrated that incorporating 30% SP into the GFFM could produce GFWS and GFIC with improved functional characteristics and satisfactory technological and sensory attributes.

Keywords: Gluten intolerance; celiac; ice cream cone.

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INTRODUCTION

The utilisation of modern technology facilitates the development of new products that respond to the increasing need for higher-quality food items and enhanced nutritional attributes. This situation is achieved by considering various factors such as consumers' eating habits, micronutrients deficiencies, and diet restrictions (Kowaleski et al., 2020; de Santana Silva et al., 2022). The changing dietary preferences of consumers suggest a growing preference for high-quality and nutritionally rich food products. The use of functional foods in dietary interventions aimed at people who have food restrictions is of significant importance. Functional foods those that are enriched with compounds with biological activity that contribute positively to health and contain important nutrients (Kowaleski et al., 2020).

Cereals are a cheap source of energy, and play an important role in our diet. Today, in addition to bread, various cereal products such as biscuits, cookies, wafers, and cakes are also offered to consumers (Gül et al., 2019). However, since celiac patients need to eat a gluten-free diet, their choice of products is limited. In addition, celiacs do not have access to fresh gluten-free products at any time, and these products can often be nutritionally deficient.

Therefore, increasing the variety of gluten-free products is an important issue (Ceylan and Muştu, 2021). Celiac disease is a popular autoimmune disorder requiring lifelong adherence to a gluten-free diet. It is estimated to impact approximately 1–2% of the global population (Gül et al., 2019; Gülhan and Karaca, 2023).

An ice cream cone, a type of wafer, is classified as a biscuit and is made from flour, fat, sugar, raising agent, and additives in varying proportions (de Santana Silva et al., 2022; Özdemir et al., 2022). Italo Marchiony initially invented the ice cream cone in 1896, and there are two different techniques to manufacture it. The first is a thin, wafer-like cone created by cooking a mixture of wheat flour, sugar, oil, and other ingredients in a pan and then shaping it into a cone. The second type produces a cone by shaping the dough into various shapes and cooking it until it achieves a crisp texture (Kushwaha et al., 2023). It was determined that various natural additives were used in the literature to evaluate the cone as a functional food. For this purpose, sorghum (Kigozi et al., 2011), sweet potato peel (Dom et al., 2020), maize flour (Rismawati et al., 2020), ragi, bajrant, amaranth, buckwheat (Mhatre et al., 2022), carob molasses (Özdemir et al., 2022), jackfruit (Kushwaha et al., 2023), and wheat milling by-products (Manikanta et al., 2023) were used to improve nutrient composition and quality. Cowpea and rice flour (da Santana Silva et al., 2022) were used to produce gluten-free cones.

In Türkiye, the production of the strawberry (*Fragaria x ananassa*), a member of the berry group, has been steadily expanding. In 2021, the total production of strawberries in Türkiye, reached 669 thousand tons. Strawberries, whose composition varies according to variety and growing conditions, contain 88–90% moisture, 0.17–0.8% ash, 1.74–3.10% protein, 0.58–1.08% dietary fibre, 0.11-0.28% fat, and 5.02–7.92% carbohydrate (Rahman et al., 2021). Furthermore, it ranks among the top 100 foods rich in dietary polyphenols. It falls under the same category as fruits like raspberries and grapes, which are known for their high anthocyanin content (Pérez-Jimenez et al., 2010; Görgüç et al., 2019). Strawberry, which contains phenolic components such as kaempferol, cyanidin, and quarsetin, also contains high levels of antioxidant components such as anthocyanins and ascorbic acid. The functional food known as strawberry shows various beneficial effects, including the reduction of blood pressure and a high level of antioxidant and anti-inflammatory properties (Basu et al., 2014; Görgüç et al., 2019). Giampieri et al. (2012) conducted a comprehensive review on the strawberry fruit's composition, nutritional quality, and effects on human health.

In recent years, strawberry cultivation worldwide and in Türkiye has gained importance in production and foreign trade. Nevertheless, strawberries are harvested at specific times of the year, and their fruit is highly vulnerable to spoilage and mechanical damage and has a short shelf life, resulting in significant economic losses (Sadowska et al., 2020). Moreover, the exorbitant expenses associated with these resources' global distribution could fuel the development of innovative alternative products. Due to these impasses of fresh strawberries, they are typically preserved by various industrial approaches such as freezing, canning, or being transformed into jam, frozen, or dried into bits, snacks, or powder (Kowalska et al., 2018). Drying is the oldest method of food preservation. Consequently, freeze-dried, spray-dried, or hot air foam-mat-dried (Farid et al., 2023) SP offers a means of preserving fresh strawberries' taste and nutritional advantages (Sadowska et al., 2020).

On the other hand, research has demonstrated that strawberry powder has numerous benefits on health. Zunino et al. (2012) reported that a 3-week SP diet intervention lowered cholesterol levels, increased LDL particle size, and decreased risk factors for cardiovascular disease, stroke, and diabetes in obese volunteers. This suggests that SP may help prevent diseases linked to obesity. Basu et al. (2009) demonstrate the potential of freeze-dried SP to reduce both total and LDL-cholesterol levels and lipid peroxidation in women diagnosed with metabolic syndrome. Similarly, Zunino et al. (2012) reported that a 3-week SP diet intervention in obese individuals reduced cholesterol levels, small HDL particles, and increased LDL particle size; reduced risk variables for cardiovascular disease, stroke, and diabetes in obese volunteers; and that strawberries may help prevent obesity-related diseases. Multiple studies, including those similar to the ones mentioned, have shown that freeze-dried SP intake improves certain markers of cardiovascular health in adults with cardiovascular risk factors; however, the data found by Djurica et al. (2016) support the concept that freeze-dried SP may provide vascular health benefits to heavier adolescent males. Preliminary studies on the effects of freeze-dried SP on vascular health are reviewed by Holt et al. (2020).

SP contains all the flavour and nutritional properties of fresh fruit and can be used as natural and safe colouring and flavouring agent that can enhance the nutritious content and natural strawberry flavour of various food items, including smoothies, candies, jelly, milkshakes, custard, yoghurt, bakery products, beverages, noodles, instant puddings, ice creams, and more (Gong ZhiQing et al., 2018; Sadowska et al., 2020; Srimiati et al., 2023). It was reported that (Monmai et al., 2021) the combination of SP and rice powder in fermented rice cake manufacture and processing could potentially serve as a source of anti-inflammatory action. The inclusion of SP had a beneficial impact on the overall sensory evaluation of dry noodles, and the proper level of addition was determined as 6% (Park et al., 2016). The addition of SP resulted in softer and more stable frozen dairy desserts over time (Bilbao-Sainz et al., 2019).

SP could be a more practical form than its raw counterparts as an antioxidant-rich flavour enhancer for food products. The examples above demonstrate the widespread use of SP in various food products. However, based on our current literature analysis, we have not found any research investigating the use of SP in producing GFWS's or

GFIC's. As a result, the current study aimed to assess SP's usability for improving GFWS's nutritional and sensory characteristics. GFWS is generated through the replacement of GFFM with SP in varying proportions (0-10-20-30%). The GFWS underwent comprehensive chemical, physical, textural, and sensory tests to investigate their suitability for use in GFIC manufacture. The study also aimed to offer a wider range of food options for individuals with celiac disease.

MATERIALS AND METHODS

Material

Corn starch and potato starch were obtained from Tat Construction Industry and Trade Inc. (İzmir, Türkiye). Rice flour and corn flour were purchased from Hüsnü Özmen Food Industry Inc. (İzmir, Türkiye), Xanthan gum was acquired from Selim Esans Deposu Chemical Materials Import and Wholesale Internal Trade Inc. (İzmir, Türkiye), and lecithin was obtained from Smart Chemical Trade and Consulting Inc. (İzmir, Türkiye). Vegetable oil and baking soda (sodium bicarbonate) were procured from Isparta local supermarkets. The SP used to enrich the GFWS was supplied from Agromica Food Agriculture Energy Industry Trade Inc. in powder and packaged form (İzmir, Türkiye).

GFWS Production Method

GFWS production was carried out according to Gül et al. (2019). The GFFM employed in the investigation was sourced from the study conducted by Hayıt and Gül (2019). The GFFM consisted of 45% potato starch, 40% rice flour, 8% corn flour, and 7% corn starch. In the production of GFWS, SP was added in 4 different proportions (0-10-20-30%) according to the principle of substitution with GFFM. Table 1 displays the components and quantities used in the production of GFWS.

Table 1. Ingredients used in the production of GFWS†

Sample	GFFM† (g)	SP† (g)	Water (ml)	Vegetable oil (ml)	Salt (g)	Sodium bicarbonate (g)	Lecithin (g)	Xanthan gum (g)
GFWS-0	100	0	155	1	0.5	0.4	0.5	60
GFWS-10	90	10	155	1	0.5	0.4	0.5	60
GFWS-20	80	20	155	1	0.5	0.4	0.5	60
GFWS-30	70	30	155	1	0.5	0.4	0.5	60

Note: †:GFWS: Gluten-Free Wafer Sheet, GFFM: Gluten-Free Flour Mixture (45% potato starch, 40% rice flour, 8% corn flour, and 7% corn starch); SP: Strawberry Flour.

In the preparation of gluten free wafer dough to be used for GFFS, firstly, water was placed in the mixing chamber of a Hobart mixer (Model N50CF, Hobart, Germany). Following the addition of salt and sodium bicarbonate to the water, manual mixing was employed as the initial step to ensure proper dissolution. Subsequently, a GFFM vegetable oil, and lecithin were incorporated into the aforementioned mixture and kneaded for 4 minutes. For the manufacturing of each GFFS, a portion of 20 grams of dough was taken out of the prepared wafer dough. This dough was then subjected to baking in a laboratory-type wafer baking machine (Remta, KT1 Cornet Machine, REMTA Machina Import-Export Industry and Trade Limited Company, İstanbul Türkiye) at a temperature of 250 °C for 90 seconds. The wafer doughs were baked into circular wafer sheets and after baking they were left to cool at room temperature for 30 minutes. The following analyses were then performed on them. For the production of GFIC's, these GFWS's were shaped manually with the cone shaping apparatus (Figure 1). The following analyses were performed on GFWS since a standard shape could not be achieved by hand shaping and a more accurate comparison could be made on GFWS. Commercial product production can yield a more uniform and standard ice cream cone shape.

Physical analysis of GFWS

To determine the physical characteristics of the GFWS utilised in the production of GFICs, the diameter and thickness of the sheets were measured using a digital caliper. The colour measurements of GFWS were obtained by utilising the Minolta CR410 (Japan) to measure the brightness (L*), redness (a*), and yellowness (b*) values at three separate places on the sheets.

Chemical analysis of GFWS

The chemical parameters of SP and GFWS were examined, including moisture (AACC Method, 44-01.01, 2000), ash (AACC Method, 08-01.01, 2000), total dietary fibre content (AACC Method, 32-07.01, 2000), pH level (AACC Method, 02-52.01, 2000), and water activity.

Textural analysis in GFWS

The hardness and fracturability of the GFWS were measured using a texture analyzer (TA-XT2, Stable Micro Systems, Surrey, UK, 5 kg load cell) equipped with a three-point bending rig (HDP/3 PB). The test parameters used in the analysis are as follows: The pre-test speed was 1.0 mm/s, the test speed was 3.0 mm/s, the post-test speed was 10.0 mm/s, the distance was 5 mm, and the trigger force was auto-50 g (Gül et al., 2019).

Sensory analysis of GFWS

A group of 10 semi-trained panelists carried out sensory evaluation of the GFWS's. Sensory analyses were performed on GFWS's for a better comparison. Before the sensory evaluation, the panelists were informed about the sensory evaluation criteria of the GFWS's. These criteria were based on a scoring system from 1 to 5 (5 points: very good, 4 points: good, 3 points: acceptable, 2 points: not enough, 1 point: bad). The cones were evaluated in terms of surface appearance, surface color, crispness, chewiness, odor, aroma, taste/flavor, general taste and affordability. Regarding affordability, we asked the panellists the following question: "Would you buy such a product if it were commercially produced and offered for sale?" The panellists were requested to evaluate their responses using a 5-point scale, as: 1. I would definitely not purchase, 2: I would not purchase, 3: I am unsure, 4: I would purchase, and 5: I would definitely purchase it (Gül et al.2019).

Statistical Analysis

ANOVA was performed to find differences between GFWS's that were statistically significant (p 0.05). In order to determine the Duncan correlation coefficients with a 5% confidence level, SPSS (Version 16, IBM, USA) was used.

RESULTS AND DISCUSSIONS

Physical properties of GFWS

Table 2 displays the physical characteristics of GFWS, including its diameter, thickness, and colour values.

Table 2. Physical properties of GFWS†

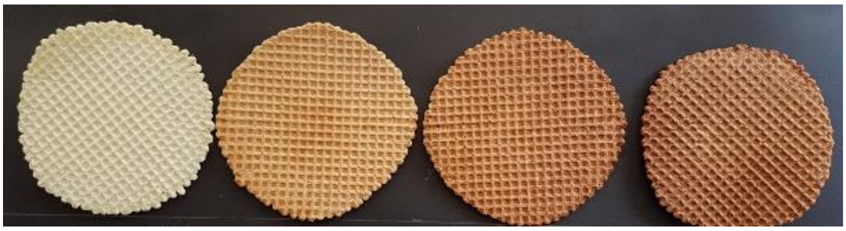
Sample	Diameter (mm)	Thickness (mm)	L*	a*	b*
GFWS-0	116.70a	2.56c	73.11a	-0.72c	18.31a
GFWS-10	111.07b	2.67ab	51.45b	10.08b	18.71a
GFWS-20	110.96c	2.70b	38.59c	9.57b	14.21b
GFWS-30	108.38d	2.76a	31.67d	11.05a	9.44c

Note: There is no statistical difference (Duncan test, $p > 0.05$). between the means shown with the same letter in the same column.

†:GFWS: Gluten-Free Wafer Sheet.

The statistical analysis indicated a statistically significant difference ($p<0.05$) between the diameter and thickness values in GFWS's. Diameter and thickness ranged from 108.38 mm to 116.70 mm and 2.56 mm to 2.76 mm. The diameter displayed a negative correlation with the rate of SP addition, resulting in a decrease. Conversely, the thickness value showed a positive correlation, leading to an increase. The control sample (without SP) shows the largest diameter, measuring 116.70 mm, whereas the GFWS-30 shows the smallest diameter, measuring 108.38 mm. In ice cream, cones produced using soy okara, an increase in the addition rate led to a similar decrease in diameter (Berezina et al., 2022). Similarly, adding fishmeal to wafers led to a decrease in diameter and an increase in thickness (Tiwari et al., 2020). While the dietary fibre content in the dry matter of fresh strawberries is 10–12%, this rate is around 60% in dried strawberries (Giampieri et al., 2012; Sójka et al., 2013). The ability of the dough to retain the appropriate amount of air during mixing depends on the density and viscosity of the dough (Özyiğit et al., 2020). Therefore, the addition of SP with a high dietary fibre content to the dough may have increased the dough density and caused the thickness to increase.

The brightness (L*) of GFWSs varied between 31.67 and 73.11. Compared to a control sample without SP, the GWFS decreased L*, as visually depicted in Figure 1. The L* values of wafer sheets exhibited a negative correlation with the increasing proportion of SP. The GFWS's redness (a*) increased as the addition rate of SP increased, while the yellowness (b*) decreased. The increase in red color may have been caused by anthocyanins in strawberries and 1.89–4.52% glucose (Kallio et al., 2000). Non-enzymatic browning may cause glucose to darken and increase redness (Figure 1). GFWS-10 was in the same statistical group as the control (SGFC0) group. GFWS-30 has the lowest b* value with 9.44. Dom et al. (2020) found that the rate of addition led to a decrease in the L* and a* values of the cones containing sweet potato peel, but an increase in the b* value Similarly, the L* value of the cones to which carob molasses pulp was added decreased depending on the rate of addition (Özdemir et al., 2022).



(a)

(b)

Figure 1. (a): Gluten free wafer sheets from left to right, GFWS-0, GFWS-10, GFWS-20, GFWS-30; (b): Samples from gluten free ice cream cones.

Chemical properties of SP and GFWS

The chemical parameters of SP and GFWS, including moisture, ash, dietary fibre content, water activity, and pH values, are provided in Table 3.

Table 3. Chemical properties of GFWS†

Sample	Moisture (%)	Ash (%)	Dietary fiber (%)	Water activity (aw)	pH
SP	12.86a	2.40a	12.08a	0.302d	3.68e
GFWS-0	8.25c	0.99e	5.50e	0.443b	7.33a
GFWS-10	9.92b	1.26d	5.98d	0.487a	5.75b
GFWS-20	7.66d	1.36c	7.13c	0.474a	4.99c
GFWS-30	5.76e	1.50b	9.70b	0.381c	4.58d

Note: There is no statistical difference (Duncan test, $p > 0.05$). between the means shown with the same letter in the same column.

†:GFWS: Gluten-Free Wafer Sheet.

The moisture content of SP was significantly higher ($p < 0.05$) than that of GFWS's. However, the GFWS with 10% SP added had a higher moisture content compared to the other samples. The moisture content of GFWSs declined significantly in inverse proportion to the SP addition rate in the samples when SP was applied at 20% and 30%. It was reported that the moisture value of wafers enriched with fish meal decreased from 7.38% in the control group to 6.61% when the addition rate increased to 30%. According to Tiwari et al. (2020), this effect could potentially be attributed to the interaction between proteins present in fish meal with a high degree of addition and polysaccharides. It may have caused a similar reaction in strawberries containing 0.75–2.28% protein (Gulen and Eris, 2004). In addition, while the moisture value increased when 10% SP was added, the moisture value decreased with the increase in the addition rate, suggesting that moisture loss may also be due to dietary fibers. The dietary fibers in SP may have damaged the gluten network's texture, making it difficult to keep moisture trapped inside and reducing the GFWS's moisture value.

The ash content of SP varies according to the type of strawberry and growing conditions. While the ash value of SP used in the study was 2.40 %, Omima et al. (2022) reported it as 3.63%. The ash value of the GFWS's without SP was 0.99% (GFWS-0). The ash content of GFWS exhibited a direct correlation with the rate of addition of SP.

The water activity of SP was found to be lower than that of GFWS samples. On the other hand, GFWS's water activity is similar to the moisture value. GFWS-10 has the highest water activity among the GFWS, measuring at 0.487, while GFWS-30 has the lowest water activity, with a value of 0.381. According to Yıldırım et al. (2018), microbial spoilage can be prevented by water activity values that are below 0.6. As shown in Table 3, the water activity values for all GFWS have been found to be below the limit of 0.6.

Strawberry is an acidic fruit with a pH value of around 3.4 (Sahari et al., 2004). The study determined the pH value of SP to be 3.68 (Table 3). The addition of SP decreased the pH value of the GFWS due to its acidic nature. GFWS-0 had a pH value of 7.33, whereas GFWS-30 had a pH value of 4.58.

The dietary fibre content of GFWS, when enriched with the addition of SP (which has a high dietary fibre content), rose proportionally to the rate of addition. GFWS-30 exhibited the highest concentration of dietary fibre. Shanmugam et al. (2017) found, in line with our results, that adding strawberry powder to a mutton patty between 3% and 5% increased the dietary fibre content compared to the control sample, which ranged between 4.11 and 5.2%.

Textural properties of GFWS

Reducing breakage in ice cream cones is crucial for both their ability to withstand the ice cream within and to keep them from fracturing while being transported. However, there is a certain crispness requirement for the cones that consumers desire. Providing these conditions depends on the ingredients used in production and their interaction with each other (Huang, 1981). The textural properties of GFWS are given in Table 4.

Table 4. Textural properties of GFWS†

Sample	Hardness (g)	Fracturability (mm)
GFWS-0	1502.24a	33.20 a
GFWS-10	1204.63b	20.02b
GFWS-20	1053.85c	19.91b
GFWS-30	683.11d	20.09b

Note: There is no statistical difference (Duncan test, $p > 0.05$). between the means shown with the same letter in the same column.

†:GFWS: Gluten-Free Wafer Sheet.

The hardness exhibited a decrease with the increasing level of SP, as shown in Table 4. On the other hand, SP substitution at different ratios in the formulation caused a significant decrease in fracturability values compared to the control. No significant difference in fracturability value ($p>0.05$) was observed when SP was added throughout different ratios. The hardness of ice cream cones, with the addition of sweet potato peel and carob molasses pulp, displayed similar changes that were dependent on the rate of addition. The hardness of the sample was found to be increased by the addition of sweet potato peel, whereas the addition of carob molasses pulp resulted in a decrease in the hardness value. Increasing flour's protein content or additives' protein content can lead to a decrease in the crispness of wafers and cones. In addition, high- fibre foods may cause the cone texture to become more crisp (Dom et al., 2020; Özdemir et al., 2022).

Sensory properties of GFWS

Figure 2 illustrates the sensory characteristics of GFWSs.

Sensory characteristics are an important factor affecting foods' marketability (Özdemir et al., 2022). GFWS's external view scores varied between 3.5 and 4.1. It was determined that there was not much difference between GFWS-0 and SP added at certain ratios. As the ratio increased, the external view first increased and then decreased. In terms of external view, the samples with SP addition were more liked by the panellists than the control sample without any SP addition. The GFWS with the 20% SP addition received the highest score. The appreciation of external appearance began to decrease as the addition rate increased to 30%. The surface colour of GFWSs varied between 2.9 and 4.0. The addition of SP caused GFWS to be liked in terms of surface color. Compared to other addition rates, the samples with a 10% SP addition were the most liked for their surface color. The crispiness properties varied between 2.4 and 3.7. As the rate escalated, we observed an increase in crispness with the addition of SP compared to the control group. 30% SP was found to be more crisp. With the addition of SP, GFWS's were more preferred in terms of aroma. The aroma category's scores also increased in parallel with the addition of SP. While the control group and the GFWS with 10% SP added scored at the same rate, it was determined that the taste/flavour ratio increased with 20–30% SP added. As the ratio increased, we observed an increase in taste and flavor. Adding SP increased general acceptability, and GFWS-20 and GFWS-30 had higher overall evaluation scores. Szymanowska et al. (2021) reported that consumers prefer traditional flavours in products such as wafers, and they stated that consumers liked the fruit flavour when 100% was added. However, the liking scores of the wafers decreased as the addition rate increased in wafers to which raspberry juice was added. The affordability values of the GFWSs containing SP were found to be considerably higher than the control sample containing no SP. The GFWSs containing 20% and 30% SP were more affordable than the samples containing 10% SP. These results indicate that SP can be used to produce GFICs at a high rate of 30%.

Figure 2. Sensory properties of GFWS (Gluten free wafer sheets).

CONCLUSIONS

This study aimed to produce GFWS with functional properties suitable for individuals with celiac disease who adhere to a gluten-free diet. Both SP and SP-added GFWS are rich sources of dietary fiber. Especially when the SP substitution rate was increased to 30%, it significantly increased the dietary fiber content of GFWS. Hence, adding SP to the formulation of GFWS resulted in changes to the physical, chemical, textural, and sensory properties. The ash content (an indicator of mineral matter) showed a positive correlation with the addition of SP, whereas the moisture content showed a negative correlation. The GFWS's color properties varied depending on the rate of addition. The addition rate had an impact on the decrease of L* and b* values, while the a* value showed an increase. Physically, the increase in the addition rate caused the thickness to increase. The addition of SP, which also affects the textural properties, decreased the hardness value and caused a reduction in brittleness of up to 20%. Even though SP increased the brittleness value by 30%, there was no statistically significant difference between the groups ($p<0.05$). In terms of sensory properties, adding SP received a higher appreciation score than the control sample. When all the properties were evaluated in general, it was determined that adding SP up to 30% substitution levels can be used in the production of GFWS and GFIC and can be preferred by consumers. We concluded that it is possible to produce a GFIC that is technologically and sensoryly acceptable as well as nutritionally rich, especially in dietary fibre, after considering the physical and chemical properties of GFWS produced with 30% SP substitution. Further research may identify the specific nutritional qualities and health benefits of ice cream cones enriched with 30% strawberry powder.

Author Contributions: H.G: Conceived and designed the analysis; H.G and S.A: Collected the data; A.N.K., E.P., N.S.S T.T and H.G.: Performed the analysis; S.A and H.G: Statistical analysis, H.G and S.A: Writing–review & editing

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Conflicts of Interest

The authors declare that they do not have any conflict of interest

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