**Development and Quality** **Evaluation of Gluten-Free Waffle Cone Prepared from Sorghum and Khandsari Sugar**

**Abstract**

This study explores the development of a gluten-free waffle cone using sorghum flour as a healthier and functional alternative to conventional wheat-based cones. Proximate composition analysis revealed that sorghum-based cones had enhanced nutritional properties, including higher moisture (3.1%), ash (2.4%), fat (12.5%), protein (10.2%), and crude fiber (3.2%) contents, along with reduced carbohydrate (67.2%) and energy values (442 kcal/100 g) compared to the control market cone. Sensory evaluation indicated that although the sorghum cone received slightly lower scores in appearance, texture, taste, and overall acceptability, it remained within an acceptable range, indicating good potential for consumer acceptance. These results highlight the nutritional advantages of sorghum flour in gluten-free product development. Implementation of these findings can aid in the formulation of healthier, gluten-free alternatives in commercial bakery and ice cream cone manufacturing, particularly benefiting consumers with celiac disease or gluten sensitivity, while also promoting the utilization of underused grains like sorghum. Overall, sorghum-based waffle cones offer a sustainable, nutrient-dense snack option that aligns with the rising demand for gluten-free and health-conscious food products.

**Keywords:** Sorghum, Gluten-free, Waffle cone, Proximate analysis, Sensory evaluation, Millet-based product, Nutritional composition

1. **Introduction**

Recent research in the food industry has focused on the pro- duction and development of functional foods with health benefit and safe for consumption and one of such development is the production of gluten-free products (Adiamo et al., 2017) . The consumption of gluten-free products is increasingly becoming a dietary trend among the general population. This shift is largely driven by scientifically unsubstantiated beliefs that avoiding gluten enhances health or that gluten is inherently harmful to humans, leading to medically unnecessary adherence to gluten-free diets (Cabanillas, 2020). Gluten intolerance, including celiac disease and non-celiac gluten sensitivity, has become a significant health concern globally (Alessio & Carlo, 2025). Celiac disease is an autoimmune disorder in which the ingestion of gluten—a protein found in wheat, barley, and rye—triggers an immune response that damages the small intestine (López Casado et al., 2018). This condition affects nutrient absorption and can lead to various complications such as anemia, osteoporosis, and delayed growth in children (Kreutz et al., 2020). As awareness increases, so does the demand for gluten-free alternatives, particularly in baked and snack products traditionally made with wheat flour (Gómez et al., 2008).

Sorghum (*Sorghum bicolor*), a gluten-free ancient cereal grain, is gaining prominence in gluten-free product development due to its rich nutritional profile and functional properties hence called food of future (Chhikara et al., 2019). It is a good source of dietary fiber, resistant starch, antioxidants (including phenolic compounds), and essential minerals such as iron and phosphorus (Tanwar et al., 2023). Sorghum flour also offers excellent binding and film-forming abilities, which are crucial for maintaining structural integrity in baked products without gluten (Curti et al., 2021). Its mild flavor and versatility make it a suitable base for products like waffles, pancakes, and cones.

*Khandsari* sugar, an unrefined traditional sweetener commonly used in India, is produced from sugarcane juice without the use of chemical refining agents. It retains some of the natural molasses, giving it a mild caramel flavor and a golden color. *Khandsari* sugar is less processed and contains trace minerals such as calcium, iron, magnesium, and potassium, distinguishing it nutritionally from refined white sugar (Agarwal et al., 2004; N et al., 2024; Singh, 2024; Venketesa Palanichamy N, 2024). Its incorporation in food products aligns with the growing consumer preference for natural, wholesome ingredients.

The use of millets such as sorghum, combined with traditional sweeteners like *Khandsari* sugar, offers a dual advantage: providing nutritionally enriched, gluten-free alternatives while preserving regional culinary heritage. Developing innovative snack products like waffle cones from these ingredients not only addresses the dietary needs of gluten-sensitive individuals but also adds value to underutilized grains and traditional ingredients.

The primary objective of this study was to develop a gluten-free waffle cone using sorghum flour and *Khandsari* sugar, focusing on creating a product suitable for individuals with gluten intolerance or celiac disease. The research aimed to evaluate the physicochemical, textural, and sensory attributes of the developed waffle cone to ensure its quality and consumer acceptability. the study sought to explore the potential of sorghum and *Khandsari* sugar as sustainable and nutritious alternatives to conventional ingredients in gluten-free snack product development.

1. **Material & Methods**

Sorghum (*Sorghum bicolor*), was procured from a local grain market in Prayagraj, Uttar Pradesh, India. The grains were milled into flour using a traditional atta chakki (flour mill) in Prayagraj. The resulting flour was packed in high-density polyethylene (HDPE) packaging material to prevent contamination and ensure quality preservation. It was stored at a Controlled temperature of 10–15°C to prevent rancidity and maintain freshness. Milk and butter were purchased from the Amul store, Prayagraj, Uttar Pradesh, India. Khandsari sugar and baking powder were sourced from local grocery markets in Prayagraj.

A Control Market cone sample of a conventional wheat-based waffle cone was procured from a commercial market in Prayagraj, Uttar Pradesh, India. This sample, made from refined wheat flour, white sugar, milk, and butter, was used for comparative analysis against the gluten-free Sorghum waffle cones.

***2.1 Development of waffle cone:***

To prepare the waffle cone, the methodology was adapted from previous studies by (Kigozi, 2011; Mhatre et al., 2022) on gluten-free waffle formulations with slight modifications. for the preparation of the waffle cone, powdered *Khandsari* sugar was taken in a bowl and mixed with melted butter. Subsequently, the dry ingredients, including baking powder with Sorghum flour, were thoroughly mixed. Milk was then incorporated into the mixture with continuous stirring until the batter achieved a soft and creamy consistency. The batter was kept standing for 10 minutes to raise the air bubble to the top. The batter was poured on the waffle cone maker pan, baked for 2 min at 180 °C temperature. Each waffle was immediately folded into a cone shape by using a cone molder after it was removed from the pan. The waffle cone was initially wrapped in butter paper and then packaged in low-density polyethylene and aluminum laminated pouches for further analysis. The flowsheet of preparation of waffle cone is as Fig 1.



**Fig 1: Step wise process for preparation of Sorghum waffle cone.**

* 1. **Proximate analysis of gluten free Sorghum based waffle cone:**

The proximate composition of the gluten-free waffle cone was determined to evaluate its nutritional profile. The analysis was conducted using standard methods outlined by the Association of Official Analytical Chemists (AOAC, 2012). Moisture content was determined using the hot-air oven method (AOAC 925.10). Protein content was analyzed using an automatic macro Kjeldahl apparatus (FOSS Inc., USA), and the nitrogen content was multiplied by a factor of 6.25 to calculate the protein content (AOAC 978.04). Fat content was estimated using the Soxhlet extraction method (AOAC 920.39). Ash content was quantified by incinerating the sample in a muffle furnace at 550°C (AOAC 930.05). Crude fiber was measured using the acid and alkali digestion method (AOAC 962.09). The carbohydrate content was calculated by the difference method. These analyses help assess the nutritional quality and stability of the product, ensuring it meets consumer expectations and dietary requirements.

* 1. **Sensory Analysis:**

According to (Mhatre et al., 2022; Urjita Patil, 2022) the nine-point Hedonic scale approach was used to assess the millet waffle ice cream cones' sensory qualities. Market ready waffle cone was used as Control Market cone sample alongside the experimental waffle cone. Five men and five women from the Department of Dairy Technology made up the ten-person, untrained panel that took part in the assessment. To guarantee randomized sample presentation, the same panel was used in three sets, totaling 13 runs. The runs were rearranged in sequence for each set. Plates containing the samples were served, and they were assessed at room temperature (30°C). The panelists evaluated the items according to their appearance, mouthfeel, taste, texture (crispiness), flavor, and general acceptability. Every panelist was knowledgeable about common sensory evaluation methods and had prior experience in food technology. Using a nine-point Hedonic scale, 1 stood for "dislike extremely" and 9 for "like extremely." To ascertain the samples' sensory acceptability, the mean scores for each attribute were computed after the scores were recorded.

* 1. **Statistical Analysis**

The experiments were performed in triplicate, and the mean values were used for statistical analysis. The data were analyzed using one-way analysis of variance (ANOVA) in Minitab to identify significant differences between the samples.

1. **Results & Discussion**

**3.1** **Proximate Analysis**

The proximate composition of the control market cone and sorghum waffle cone is presented in Table 1. The results revealed that the moisture content of the samples ranged from 2.8% in the control market cone to 3.1% in the sorghum cone. The slight increase in moisture content observed in the sorghum waffle cone may be due to the water-binding capacity of sorghum flour, which tends to retain more moisture (Dayakar Rao et al., 2016). Lower moisture content is desirable in baked products like cones as it helps in increasing shelf life and reducing microbial spoilage, as supported by (Cauvain & Young, 2010). Similar trends were observed in a study by (Borşa (Bogdan) et al., 2025) where the incorporation of rosehip waste powder in waffle cones increased the moisture content with higher substitution levels.

The ash content of the cones ranged from 1.2% in the control cone to 2.4% in the sorghum waffle cone. This increase in ash content indicates a higher mineral content in sorghum-based cones, as sorghum is known to be a good source of micronutrients such as calcium, phosphorus, and iron (Mohamed et al., 2022). These findings are in line with the results of (Tanwar et al., 2023), who reported the mineral richness of alternative flours like sorghum in functional food development.

The protein content showed a notable increase, ranging from 8.5% in the control cone to 10.2% in the sorghum cone. This increase may be attributed to the inherently higher protein content in sorghum flour as compared to refined wheat flour (Khoddami et al., 2023). Similar findings were reported by(Apostol et al., 2020), who reported that incorporation of cereal grains such as sorghum in food products can significantly improve protein levels. The increase in protein not only enhances the nutritional profile but also appeals to health-conscious consumers.

The crude fat content of the cones varied from 11.0% in the control to 12.5% in the sorghum cone. The increase may be linked to the natural fat content of sorghum or the interaction between fat and fiber content in the product matrix. sorghum is known for its diverse fatty acid profile, including oleic and linoleic acids, which contribute to its nutritional value (Desta et al., 2023) . The presence of dietary fiber in sorghum may also enhance fat absorption and metabolism, potentially leading to higher fat content in processed products (Vali Pasha et al., 2018).

The crude fiber content showed a significant increase, ranging from 0.8% in the control cone to 3.2% in the sorghum waffle cone. The high fiber content in the sorghum cone could be attributed to the bran and germ parts of sorghum, which are retained in whole grain flour (Alvarenga et al., 2018; Tanwar et al., 2023).

The carbohydrate content decreased from 75.0% in the control cone to 67.2% in the sorghum waffle cone. This reduction in carbohydrate content is likely due to the higher proportions of protein and fiber in the sorghum formulation. This observation is consistent with the report of (P. Pontieri, 2016) , who noted that carbohydrate levels tend to decrease when composite flours with higher protein and fiber are used.

The energy value of the cones ranged from 442 kcal/100 g in the sorghum cone to 470 kcal/100 g in the control cone. The decrease in energy content in the sorghum cone may be due to the lower carbohydrate and slightly higher moisture levels (Rumler et al., 2022). Nonetheless, the sorghum waffle cone still provides an adequate amount of energy and meets the daily energy requirements of most age groups (Tanwar et al., 2023).

***Table 1. Proximate composition of Control Market cone and Sorghum waffle cones***

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Control Market Cone** | **Sorghum** |
| Moisture Content (%) | 2.8 ± 0.2 | *3.1 ± 0.2* |
| Ash Content (%) | 1.2 ± 0.1 | *2.4 ± 0.1* |
| Crude Fat (%) | 11.0 ± 0.5 | *12.5 ± 0.5* |
| Protein Content (%) | 8.5 ± 0.3 | *10.2 ± 0.3* |
| Crude Fiber (%) | 0.8 ± 0.1 | *3.2 ± 0.2* |
| Carbohydrates (%) | 75.0 ± 0.5 | *67.2 ± 0.5* |
| Energy Value (kcal) | 470 ± 5 | *442 ± 5* |

Each value represents the average of three determinations±SD.

**3.2 Sensory analysis:**

The sensory evaluation results of the sorghum-based gluten-free waffle cone compared to the control cone (wheat-based) indicate statistically and nutritionally significant differences across multiple sensory attributes. While both products were acceptable to the sensory panel, the control cone consistently received higher scores, reflecting the influence of wheat flour's functional properties in baked products.

**Appearance and Color**

The control cone achieved significantly higher scores for appearance (8.6 ± 0.10) and color (8.5 ± 0.11) compared to the sorghum cone (7.6 ± 0.14 and 7.6 ± 0.13, respectively). This may be attributed to the lighter, uniform golden-brown color and smooth surface typically produced by wheat-based batters due to the Maillard reaction and caramelization of sugars. In contrast, sorghum flour, being naturally darker and richer in polyphenols, often results in darker products with less visually appealing surface characteristics. Additionally, sorghum lacks gluten, which may affect the spread and smoothness during baking, leading to an irregular or less glossy finish.

**Texture and Crispiness**

Texture and crispiness are critical sensory parameters for waffle cones. The control cone was rated higher in both texture (8.7 ± 0.09) and crispiness (8.7 ± 0.10) compared to the sorghum cone (7.6 ± 0.13 and 7.6 ± 0.14). The superior textural attributes in the control cone are primarily due to the presence of gluten, which provides elasticity, structural integrity, and desirable bite characteristics. Sorghum flour, being gluten-free, lacks this viscoelastic network, leading to a denser and more brittle structure. Additionally, sorghum has a different starch composition and lower swelling capacity, which may reduce air incorporation during batter preparation, ultimately affecting crispiness and texture.

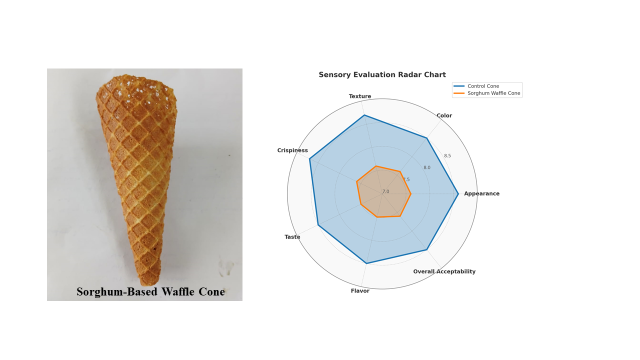
**Taste and Flavor**

The control cone scored better in taste (8.5 ± 0.12) and flavor (8.5 ± 0.12) than the sorghum cone (7.5 ± 0.15 and 7.5 ± 0.14, respectively). This difference may be attributed to the characteristic earthy and slightly bitter notes of sorghum, which some panelists may find less palatable. Moreover, the absence of gluten may limit flavor retention, while the bran content and phenolic compounds present in whole-grain sorghum can contribute to astringency or aftertaste. These issues may be mitigated through formulation strategies such as partial substitution with milder flours, use of natural sweeteners, or flavor enhancers.

**Overall Acceptability**

The overall acceptability of the control cone (8.5 ± 0.12) was higher than that of the sorghum cone (7.6 ± 0.13). While the sorghum cone was found acceptable by the panel, the lower score suggests room for improvement. These findings align with previous studies where gluten-free bakery products, although nutritionally beneficial, tend to underperform in sensory attributes compared to conventional wheat-based products due to differences in dough rheology, moisture retention, and baking performance.

These findings are in alignment with previous studies, particularly the work of (Kigozi, 2011, 2015, 2016) who reported similar results in the development of sorghum-based ice cream cones.



**Fig. 2 Sensory analysis of gluten free Sorghum waffle cone compared with control cone**

1. **Summary & Conclusion**

This study demonstrates that sorghum flour can be effectively used in the formulation of gluten-free waffle cones, offering a nutritious alternative to conventional wheat-based cones. The sorghum-based cone showed higher levels of protein, fiber, ash, and fat, enhancing its health benefits. Although it scored slightly lower in sensory attributes like appearance, texture, and flavor—mainly due to the absence of gluten and its darker color—its overall acceptability remained within acceptable limits. To address sensory limitations, future research may explore blending sorghum with other gluten-free flours, adding natural flavor enhancers, and applying improved processing techniques. Further studies on shelf life, packaging, and consumer preferences can help boost its market potential. Sorghum-based waffle cones thus represent a promising gluten-free, nutrient-rich product that supports modern dietary needs and encourages millet-based innovations aligned with sustainable food systems.

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**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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