World Journal of Food Science
www.worldfoodsciencejournal.com
Online ISSN:
Received: 08-07-2025, Accepted: 07-08-2025, Published: 22-08-2025
Volume 1, Issue 1, Jul-Sep, 2025, Page No. 19-25

Development and nutritional evaluation of wheatgrass powder incorporated functional foods

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Abstract
Wheatgrass (Triticum aestivum) is recognised as a nutrient-dense superfood, rich in vitamins, minerals, antioxidants, and bioactive compounds, offering significant health benefits. This study focuses on the development and nutritional evaluation of functional foods incorporated with wheatgrass powder to enhance their nutritional profile and therapeutic potential. Wheatgrass powder was incorporated into three food products—cookies, smoothies, and energy bars—at varying concentrations (5%, 10%, and 15%). The developed products were evaluated for their proximate composition (moisture, protein, fat, fiber, ash, and carbohydrates), antioxidant activity (DPPH radical scavenging assay), total phenolic content, and sensory acceptability using a 9-point hedonic scale. Results indicated that wheatgrass incorporation significantly increased the protein (8.5–12.3%), fibre (3.2–6.8%), and ash content (1.5–2.8%) compared to control samples, while enhancing antioxidant activity (up to 78% DPPH inhibition at 15% incorporation). Total phenolic content ranged from 120 to 350 mg GAE/100g across products, with higher values at increased wheatgrass levels. Sensory analysis revealed that products with 10% wheatgrass powder maintained acceptable taste, texture, and overall quality, with cookies scoring highest (7.8/9). The study demonstrates that wheatgrass powder can be effectively incorporated into functional foods to improve nutritional value and antioxidant properties without compromising sensory attributes at optimal levels. These findings suggest that wheatgrass-enriched products could serve as viable options for health-conscious consumers, promoting the use of superfoods in everyday diets. Further research is recommended to explore shelf-life stability and long-term health impacts of regular consumption.

Keywords: Wheatgrass powder, functional foods, nutritional evaluation, antioxidant activity, sensory acceptability, proximate composition, total phenolic content

Introduction

Addressing the growing demand for foods that promote wellness and prevent chronic diseases. The incorporation of nutrient-rich, bioactive ingredients into food products is a promising strategy to enhance their nutritional and therapeutic value. Wheatgrass, the young shoots of Triticum aestivum, has emerged as a popular superfood owing to its rich composition of vitamins (A, C, E, and B-complex), minerals (iron, calcium, magnesium, and potassium), enzymes, chlorophyll, and antioxidants. These components contribute to its reported benefits, including improved immunity, detoxification, anti-inflammatory effects, and potential anti-cancer properties. Wheatgrass is typically consumed as fresh juice, powder, or supplements, but its integration into everyday food products remains underexplored, presenting an opportunity to develop innovative functional foods.

The global functional food market is projected to grow significantly, driven by increasing consumer awareness of health and nutrition. However, challenges such as palatability, sensory acceptability, and nutritional stability must be addressed when incorporating bioactive ingredients like wheatgrass into food matrices. Wheatgrass powder, obtained by drying and grinding young wheatgrass shoots, retains most of its nutritional and bioactive properties, making it a versatile ingredient for food fortification. Previous studies have highlighted wheatgrass's high antioxidant capacity, attributed to phenolic compounds, flavonoids, and chlorophyll, which combat oxidative stress and reduce the risk of chronic diseases such as cardiovascular disorders and diabetes. Despite its potential, limited research exists on the systematic development and nutritional evaluation of wheatgrass-incorporated food products, particularly regarding their proximate composition, antioxidant activity, and consumer acceptability.

This study aims to develop functional food products—specifically cookies, smoothies, and energy bars—enriched with wheatgrass powder at varying concentrations (5%, 10%, and 15%) and evaluate their nutritional and sensory properties. Cookies were chosen for their widespread consumption and potential as a vehicle for nutrient delivery, smoothies for their compatibility with health-focused diets, and energy bars for their appeal to fitness enthusiasts. The objectives include analysing the proximate composition (moisture, protein, fat, fibre, ash, and carbohydrates), antioxidant activity (via DPPH radical scavenging assay), total phenolic content, and sensory attributes (using a 9-point hedonic scale) of the developed products. The study also investigates the impact of wheatgrass incorporation levels on the nutritional enhancement and sensory acceptability of these foods, aiming to identify optimal formulations that balance health benefits with consumer preferences.

The nutritional evaluation of wheatgrass-incorporated foods is critical to understanding their potential as functional foods. Proximate analysis provides insights into macronutrient content, which is essential for assessing the overall nutritional value of the products. For instance, wheatgrass is known to contribute dietary fibre and protein, which are vital for digestive health and muscle maintenance, respectively. Antioxidant activity, measured through the

DPPH assay, reflects the capacity of the products to neutralise free radicals, a key factor in preventing oxidative stress-related diseases. Total phenolic content, a marker of bioactive compounds, further indicates the health-promoting potential of the foods. Sensory evaluation is equally important, as consumer acceptance is a major determinant of a product's market success. Wheatgrass's characteristic grassy flavour and green colour can pose challenges to sensory acceptability, necessitating careful formulation to achieve a balance between health benefits and palatability.

Previous research has demonstrated the feasibility of incorporating superfoods into various food products. For example, spirulina and chia seeds have been successfully used in baked goods and beverages to enhance nutritional profiles. However, wheatgrass presents unique challenges due to its strong flavour and potential impact on food texture. Studies on wheatgrass incorporation are sparse, with most focusing on its use in beverages or supplements rather than solid food matrices. This study bridges this gap by exploring wheatgrass powder's application in diverse food products, providing a comprehensive analysis of their nutritional and sensory outcomes. The findings are expected to contribute to the growing body of knowledge on functional food development and support the food industry in creating health-promoting products that align with consumer trends.

The methodology involves preparing wheatgrass powder under controlled conditions to preserve its bioactive compounds, followed by its incorporation into the selected food products. The products are subjected to standardised analytical methods, including AOAC protocols for proximate analysis, spectrophotometric methods for antioxidant activity and phenolic content, and sensory evaluation by a trained panel. Statistical analysis, including ANOVA and post-hoc tests, is used to determine significant differences among formulations. This study also considers practical implications, such as cost-effectiveness and scalability, to ensure the developed products are viable for commercial production.

In conclusion, the development of wheatgrass powder-incorporated functional foods offers a promising avenue for enhancing the nutritional quality of everyday foods. By addressing both nutritional and sensory aspects, this study aims to provide a foundation for the food industry to innovate and meet the demands of health-conscious consumers. The outcomes are expected to highlight the potential of wheatgrass as a functional ingredient and encourage further research into its applications in diverse food systems.

Methods

Preparation of Wheatgrass Powder

Fresh wheatgrass (Triticum aestivum) was sourced from a local organic farm and harvested at 7–10 days post-germination to ensure optimal nutrient content. The wheatgrass was thoroughly washed with potable water to remove soil and debris, followed by rinsing with a 0.1% sodium hypochlorite solution to reduce microbial load.

Development of Functional Food Products

Three food products—cookies, smoothies, and energy bars—were formulated with wheatgrass powder at incorporation levels of 5%, 10%, and 15% (w/w for solid products, w/v for smoothies). Control samples (0% wheatgrass) were prepared for comparison.

- **Cookies:** The cookie formulation consisted of wheat flour (60%), sugar (20%), butter (15%), baking powder (1%), and water (4%). Wheatgrass powder replaced wheat flour at the specified levels. Ingredients were mixed to form a dough, rolled to a thickness of 5 mm, cut into 5 cm diameter rounds, and baked at 180°C for 15 minutes in a convection oven.

- **Smoothies:** The smoothie base included banana (40%), milk (50%), and honey (5%). Wheatgrass powder was blended into the mixture at 5%, 10%, and 15% (w/v). The smoothies were homogenised at 10,000 rpm for 2 minutes to ensure uniform dispersion.

- **Energy Bars:** The energy bar formulation comprised oats (40%), peanut butter (20%), honey (20%), and dried fruits (20%). Wheatgrass powder replaced oats at the specified levels. The mixture was pressed into moulds and set at 4°C for 4 hours before cutting into 10 cm x 3 cm bars.

All products were prepared in triplicate under controlled conditions to ensure consistency.

Proximate Analysis

The proximate composition of the developed products (moisture, protein, fat, fibre, ash, and carbohydrates) was determined using standard AOAC methods. Moisture content was measured by oven-drying at 105°C (AOAC 934.01). Crude protein was quantified using the Kjeldahl method (AOAC 978.04), with a nitrogen-to-protein conversion factor of 6.25. Fat content was determined via Soxhlet extraction (AOAC 920.39). Crude fibre was assessed using the gravimetric method (AOAC 962.09). Ash content was measured by incineration at 550°C (AOAC 923.03). Carbohydrate content was calculated by difference: 100 − (moisture + protein + fat + fibre + ash).

Sensory Evaluation

Sensory acceptability was assessed by a panel of 30 semi-trained panelists (aged 18–40 years) using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Attributes evaluated included appearance, taste, texture, aroma, and overall acceptability. Samples were coded and presented randomly to avoid bias. Panelists were provided with water and unsalted crackers to cleanse their palates between samples.

Results

Proximate Composition

The proximate analysis revealed significant enhancements in the nutritional profile of wheatgrass-incorporated functional foods compared to control samples (Table 1). The incorporation of wheatgrass powder increased moisture, protein, fiber, and ash content, while fat and carbohydrate content showed varying trends depending on the product type and incorporation level.

- **Cookies:** The moisture content of cookies ranged from 5.2 ± 0.3% (control) to 6.8 ± 0.4% (15% wheatgrass), reflecting the hygroscopic nature of wheatgrass powder. Protein content increased significantly ($p < 0.05$) from 6.3 ± 0.2% in the control to 9.8 ± 0.3% at 15% incorporation, attributed to wheatgrass's high protein content (approximately 20% on a dry basis). Crude fiber content rose from 1.2 ± 0.1% (control) to 4.5 ± 0.2% (15% wheatgrass), enhancing the dietary fiber profile. Ash content, indicative of mineral content, increased from 1.0 ± 0.1% to 2.3 ± 0.2%. Fat content remained relatively stable (14.5 ± 0.3% to 14.8 ± 0.4%), as wheatgrass powder is low in lipids. Carbohydrate content decreased from 71.8 ± 0.5% (control) to 62.6 ± 0.6% (15% wheatgrass) due to the replacement of wheat flour with lower-carbohydrate wheatgrass powder.

- **Smoothies:** Smoothies exhibited higher moisture content (80.5 ± 0.6% to 83.2 ± 0.7%) due to their liquid nature, with no significant increase with wheatgrass incorporation ($p > 0.05$). Protein content increased from 3.5 ± 0.2% (control) to 5.2 ± 0.3% (15% wheatgrass).

- Fiber content rose from 0.8 ± 0.1% to 2.5 ± 0.2%, and ash content increased from 0.6 ± 0.1% to 1.5 ± 0.1%. Fat content was low (1.2 ± 0.1% to 1.4 ± 0.1%), consistent with the low-fat nature of the smoothie base. Carbohydrates decreased from 14.4 ± 0.4% to 10.2 ± 0.3% as wheatgrass replaced carbohydrate-rich ingredients.

- **Energy Bars:** Energy bars showed a moisture content increase from 10.2 ± 0.3% (control) to 12.5 ± 0.4% (15% wheatgrass). Protein content rose from 8.7 ± 0.3% to 12.3 ± 0.4%, and fiber content increased significantly from 2.5 ± 0.2% to 6.8 ± 0.3%. Ash content increased from 1.2 ± 0.1% to 2.8 ± 0.2%. Fat content showed a slight increase (18.5 ± 0.4% to 19.2 ± 0.5%) due to the peanut butter base, while carbohydrates decreased from 59.1 ± 0.6% to 48.4 ± 0.5%.

These results indicate that wheatgrass incorporation significantly enhances the nutritional quality of all products, particularly in terms of protein, fiber, and mineral content, making them suitable for health-conscious diets.

Table 1: Proximate Composition of Wheatgrass-Incorporated Functional Foods

Product	Wheatgrass (%)	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Carbohydrates (%)
Cookies	0	5.2 ± 0.3	6.3 ± 0.2	14.5 ± 0.3	1.2 ± 0.1	1.0 ± 0.1	71.8 ± 0.5
	5	5.8 ± 0.3	7.5 ± 0.2	14.6 ± 0.3	2.0 ± 0.1	1.4 ± 0.1	68.7 ± 0.5
	10	6.3 ± 0.4	8.6 ± 0.3	14.7 ± 0.4	3.2 ± 0.2	1.8 ± 0.2	65.4 ± 0.6
	15	6.8 ± 0.4	9.8 ± 0.3	14.8 ± 0.4	4.5 ± 0.2	2.3 ± 0.2	62.6 ± 0.6
Smoothies	0	80.5 ± 0.6	3.5 ± 0.2	1.2 ± 0.1	0.8 ± 0.1	0.6 ± 0.1	14.4 ± 0.4
	5	81.0 ± 0.6	4.0 ± 0.2	1.3 ± 0.1	1.2 ± 0.1	0.9 ± 0.1	12.6 ± 0.4
	10	82.0 ± 0.7	4.6 ± 0.3	1.3 ± 0.1	1.8 ± 0.2	1.2 ± 0.1	11.1 ± 0.3
	15	83.2 ± 0.7	5.2 ± 0.3	1.4 ± 0.1	2.5 ± 0.2	1.5 ± 0.1	10.2 ± 0.3
Energy Bars	0	10.2 ± 0.3	8.7 ± 0.3	18.5 ± 0.4	2.5 ± 0.2	1.2 ± 0.1	59.1 ± 0.6
	5	10.8 ± 0.3	9.8 ± 0.3	18.7 ± 0.4	3.8 ± 0.2	1.6 ± 0.2	55.3 ± 0.5
	10	11.5 ± 0.4	11.0 ± 0.4	18.9 ± 0.5	5.2 ± 0.3	2.2 ± 0.2	51.2 ± 0.5
	15	12.5 ± 0.4	12.3 ± 0.4	19.2 ± 0.5	6.8 ± 0.3	2.8 ± 0.2	48.4 ± 0.5

Antioxidant Activity

The DPPH radical scavenging assay demonstrated a dose-dependent increase in antioxidant activity with higher wheatgrass incorporation (Figure 1).

- **Cookies:** The control cookies exhibited 15.3 ± 1.2% DPPH inhibition, which increased to 45.6 ± 2.1% (5%), 62.4 ± 2.5% (10%), and 75.8 ± 2.8% (15%). The significant increase ($p < 0.05$) reflects the contribution of wheatgrass's phenolic compounds and chlorophyll.

- **Smoothies:** Antioxidant activity rose from 20.5 ± 1.5% (control) to 50.2 ± 2.3% (5%), 68.7 ± 2.7% (10%), and 78.4 ± 3.0% (15%). The higher activity in smoothies compared to cookies may be due to better extraction of bioactive compounds in a liquid matrix.

- **Energy Bars:** The control bars showed 25.7 ± 1.8% inhibition, increasing to 48.9 ± 2.2% (5%), 65.3 ± 2.6% (10%), and 77.2 ± 2.9% (15%). The high baseline activity in control bars is attributed to the antioxidant properties of oats and dried fruits.

The results suggest that wheatgrass significantly enhances the free radical scavenging capacity of all products, with the 15% incorporation level yielding the highest activity across all formulations.

Total Phenolic Content

Total phenolic content (TPC) increased significantly ($p < 0.05$) with wheatgrass incorporation (Table 2).

- **Cookies:** TPC ranged from 85 ± 5 mg GAE/100g (control) to 120 ± 6 mg GAE/100g (5%), 200 ± 8 mg GAE/100g (10%), and 280 ± 10 mg GAE/100g (15%).

- **Smoothies:** TPC was higher, ranging from 100 ± 6 mg GAE/100g (control) to 150 ± 7 mg GAE/100g (5%), 250 ± 9 mg GAE/100g (10%), and 350 ± 12 mg GAE/100g (15%). The liquid matrix likely facilitated better phenolic extraction.

- **Energy Bars:** TPC increased from 110 ± 6 mg GAE/100g (control) to 140 ± 7 mg GAE/100g (5%), 220 ± 9 mg GAE/100g (10%), and 320 ± 11 mg GAE/100g (15%).

The higher TPC in wheatgrass-incorporated products correlates strongly with their antioxidant activity, confirming the role of phenolic compounds in enhancing shealth benefits.

Table 2: Total Phenolic Content of Wheatgrass-Incorporated Functional Foods

Product	Wheatgrass (%)	TPC (mg GAE/100g)
Cookies	0	85 ± 5
	5	120 ± 6
	10	200 ± 8
	15	280 ± 10
Smoothies	0	100 ± 6
	5	150 ± 7
	10	250 ± 9
	15	350 ± 12
Energy Bars	0	110 ± 6
	5	140 ± 7
	10	220 ± 9
	15	320 ± 11

Sensory Evaluation

Sensory evaluation results (Table 3) indicated that wheatgrass incorporation influenced acceptability, with optimal results at 10% incorporation.

- **Cookies:** The control cookies scored highest in overall acceptability (8.2 ± 0.4), followed by 5% (7.9 ± 0.3), 10% (7.8 ± 0.3), and 15% (6.5 ± 0.4). The grassy flavor and green color at 15% reduced taste and appearance scores (6.2 ± 0.4 and 6.0 ± 0.3, respectively), though texture remained acceptable (7.0 ± 0.3).

- **Smoothies:** The control smoothies scored 8.0 ± 0.4, with 5% (7.7 ± 0.3) and 10% (7.5 ± 0.3) maintaining high acceptability. The 15% smoothies scored lower (6.8 ± 0.4) due to a pronounced grassy taste and thicker texture (6.5 ± 0.3).

- **Energy Bars:** Control bars scored 7.9 ± 0.4, with 5% (7.6 ± 0.3) and 10% (7.4 ± 0.3) being well-received. The 15% bars scored 6.3 ± 0.4, with lower taste (6.0 ± 0.3) and aroma (6.1 ± 0.3) scores due to wheatgrass's strong flavor.

The 10% incorporation level was identified as optimal, balancing nutritional enhancement with sensory acceptability across all products.

Table 3: Sensory Evaluation Scores (9-Point Hedonic Scale)

Product	Wheatgrass (%)	Appearance	Taste	Texture	Aroma	Overall Acceptability
Cookies	0	8.3 ± 0.4	8.4 ± 0.4	8.2 ± 0.3	8.1 ± 0.4	8.2 ± 0.4
	5	8.0 ± 0.3	8.0 ± 0.3	7.9 ± 0.3	7.8 ± 0.3	7.9 ± 0.3
	10	7.7 ± 0.3	7.8 ± 0.3	7.8 ± 0.3	7.6 ± 0.3	7.8 ± 0.3
	15	6.0 ± 0.3	6.2 ± 0.4	7.0 ± 0.3	6.5 ± 0.4	6.5 ± 0.4
Smoothies	0	8.1 ± 0.4	8.2 ± 0.4	8.0 ± 0.3	8.0 ± 0.4	8.0 ± 0.4
	5	7.8 ± 0.3	7.8 ± 0.3	7.7 ± 0.3	7.7 ± 0.3	7.7 ± 0.3
	10	7.5 ± 0.3	7.5 ± 0.3	7.4 ± 0.3	7.4 ± 0.3	7.5 ± 0.3
	15	6.5 ± 0.3	6.5 ± 0.4	6.5 ± 0.3	6.6 ± 0.3	6.8 ± 0.4
Energy Bars	0	7.8 ± 0.4	8.0 ± 0.4	7.9 ± 0.3	7.9 ± 0.4	7.9 ± 0.4
	5	7.6 ± 0.3	7.7 ± 0.3	7.6 ± 0.3	7.6 ± 0.3	7.6 ± 0.3
	10	7.4 ± 0.3	7.5 ± 0.3	7.4 ± 0.3	7.3 ± 0.3	7.4 ± 0.3
	15	6.2 ± 0.3	6.0 ± 0.3	6.8 ± 0.3	6.1 ± 0.3	6.3 ± 0.4

Discussion of Results

The proximate analysis confirms that wheatgrass powder significantly enhances the nutritional profile of functional foods, particularly in protein, fiber, and ash content. The increase in protein (up to 12.3% in energy bars) and fiber (up to 6.8% in energy bars) aligns with wheatgrass's known composition, making these products suitable for addressing dietary deficiencies. The slight increase in moisture content, especially in cookies and energy bars, suggests that wheatgrass's hygroscopic properties may require adjustments in formulation or storage to maintain shelf life.

The antioxidant activity results highlight wheatgrass's potent free radical scavenging capacity, with smoothies showing the highest activity (78.4% at 15%) due to better solubility of bioactive compounds in a liquid matrix. The correlation between TPC and antioxidant activity ($R^2 = 0.92$, $p < 0.01$) underscores the role of phenolic compounds in the health benefits of these products. The TPC values (up to 350 mg GAE/100g in smoothies) are comparable to other superfood-incorporated products, such as spirulina-enriched beverages.

Sensory evaluation indicates that 10% wheatgrass incorporation is the optimal level for consumer acceptability, as higher levels (15%) resulted in reduced scores due to the grassy flavor and green color. Cookies performed best overall, likely due to the masking effect of sugar and butter on wheatgrass's flavor. These findings suggest that careful formulation is necessary to balance nutritional benefits with sensory appeal.

In conclusion, wheatgrass powder can be effectively incorporated into functional foods to enhance their nutritional and antioxidant properties. The 10% incorporation level offers a practical compromise for commercial applications, providing significant health benefits while maintaining consumer acceptability. Further studies are needed to assess shelf-life stability and long-term health impacts.

Discussion

The development and nutritional evaluation of wheatgrass powder-incorporated functional foods—cookies, smoothies, and energy bars—demonstrate the potential of wheatgrass as a versatile ingredient for enhancing the nutritional and therapeutic properties of everyday food products. The results of this study align with the growing interest in functional foods that combine nutritional benefits with consumer acceptability, addressing the rising demand for health-promoting dietary options. The significant improvements in proximate composition, antioxidant activity, total phenolic content, and sensory attributes observed in this study provide valuable insights into the feasibility and challenges of incorporating wheatgrass powder into diverse food matrices.

Proximate Composition

The proximate analysis revealed that wheatgrass incorporation significantly enhanced the protein, fiber, and ash content of all products, with notable increases at higher incorporation levels (15%). For instance, protein content in energy bars increased from 8.7% to 12.3%, and fiber content rose from 2.5% to 6.8%, aligning with wheatgrass's reported composition of approximately 20% protein and high dietary fiber (Kulkarni *et al*., 2006) [11]. These enhancements are particularly relevant for addressing dietary deficiencies, as protein and fiber are critical for muscle maintenance and digestive health, respectively (Slavin, 2013) [20]. The increase in ash content (up to 2.8% in energy bars) reflects wheatgrass's rich mineral profile, including calcium, iron, and magnesium, which are essential for bone health, oxygen transport, and enzymatic functions (Chauhan, 2014) [6].

The slight increase in moisture content, particularly in cookies (5.2% to 6.8%) and energy bars (10.2% to 12.5%), is attributed to wheatgrass powder's hygroscopic nature, which may absorb ambient moisture during processing (Singh *et al*., 2012) [19]. This observation suggests the need for careful formulation adjustments, such as reducing water content in dough or using moisture-barrier packaging, to ensure shelf-life stability. The reduction in carbohydrate content (e.g., from 71.8% to 62.6% in cookies) is due to the partial replacement of carbohydrate-rich ingredients (e.g., wheat flour, oats) with wheatgrass powder, which has a lower carbohydrate content. This aligns with the trend toward low-carbohydrate diets, making these products appealing to health-conscious consumers (Brouns, 2018) [5]. Compared to other superfood-incorporated products, such as spirulina-enriched cookies (protein increase of 1–2%) or chia seed bars (fiber increase of 2–3%), wheatgrass incorporation resulted in more substantial nutritional enhancements (Ghafoor *et al*., 2020; Onwulata *et al*., 2010) [8, 15]. However, the low-fat content of wheatgrass limited its impact on the fat profile of the products, which remained stable in cookies and smoothies but slightly increased in energy bars due to the peanut butter base. This suggests that wheatgrass is best suited for enhancing protein, fiber, and mineral content rather than altering fat composition.

Antioxidant Activity and Total Phenolic Content

The dose-dependent increase in antioxidant activity (up to 78.4% DPPH inhibition in smoothies at 15% wheatgrass) and total phenolic content (up to 350 mg GAE/100g in smoothies) highlights wheatgrass's potent bioactive properties. These results are consistent with previous studies reporting wheatgrass's high levels of phenolic compounds, flavonoids, and chlorophyll, which contribute to its free radical scavenging capacity (Sharma *et al*., 2015; Bar-Sela *et al*., 2015) [18]. The strong correlation between total phenolic content and antioxidant activity ($R^2 = 0.92$, $p < 0.01$) underscores the role of phenolics as primary contributors to the antioxidant potential of these products.

Smoothies exhibited the highest antioxidant activity and phenolic content, likely due to the liquid matrix facilitating better extraction of bioactive compounds during analysis (Mujoriya & Bodla, 2011) [14]. This is supported by studies on other superfood beverages, such as moringa-based smoothies, which showed higher antioxidant activity in liquid formulations compared to solid matrices (Verma *et al*., 2019) [22]. The antioxidant activity of wheatgrass-incorporated products (45.6–78.4% DPPH inhibition) is comparable to or higher than that of other functional foods, such as green tea-infused cookies (60% inhibition) or blueberry bars (65% inhibition) (Gramza-Michałowska *et al*., 2016) [9]. These findings suggest that wheatgrass-enriched foods could play a significant role in reducing oxidative stress, a key factor in chronic diseases like cardiovascular disorders and diabetes (Lobo *et al*., 2010) [13].

The increase in total phenolic content with higher wheatgrass incorporation (e.g., 280–350 mg GAE/100g at 15%) is notable when compared to baseline values in control samples (85–110 mg GAE/100g). This aligns with wheatgrass's reported phenolic content of 200–400 mg GAE/100g, depending on processing conditions (Akbas *et al*., 2017 [1]. However, the thermal processing of cookies (baking at 180°C) may have reduced the retention of heat-sensitive phenolics, explaining the slightly lower TPC in cookies compared to smoothies and energy bars (Sharma & Gujral, 2014) [17]. Future studies could explore low-temperature processing techniques, such as freeze-drying or cold-pressing, to maximize phenolic retention.

Sensory Evaluation

Sensory evaluation revealed that 10% wheatgrass incorporation was optimal for balancing nutritional benefits with consumer acceptability, as higher levels (15%) resulted in reduced scores for taste, appearance, and aroma due to wheatgrass's grassy flavor and green color. Cookies achieved the highest overall acceptability (7.8/9 at 10%), likely due to the masking effect of sugar and butter, which mitigated the bitterness of wheatgrass (Kulkarni *et al*., 2007) [12]. Smoothies and energy bars at 10% also scored well (7.5/9 and 7.4/9, respectively), but the 15% level led to lower scores (6.5–6.8/9), particularly for taste and aroma, consistent with sensory challenges reported for other green superfoods like spirulina (Batista *et al*., 2017) [3].

The sensory results highlight a critical challenge in functional food development: achieving a balance between health benefits and palatability. The grassy flavor and green hue of wheatgrass, while indicative of its chlorophyll content, can negatively impact consumer perception, particularly in solid matrices like cookies and energy bars (Hossain *et al*., 2017) [10]. Strategies such as flavor masking with natural sweeteners (e.g., stevia, vanilla) or color blending with complementary ingredients (e.g., cocoa powder) could improve acceptability at higher incorporation levels. The high acceptability of cookies suggests they are a promising vehicle for wheatgrass delivery, as baked goods are widely consumed and can be formulated to minimize sensory drawbacks (Gawlik-Dziki *et al*., 2013) [7].

Practical Implications

The findings have significant implications for the food industry, particularly in the context of the growing functional food market, projected to reach $275 billion by 2025 (Statista, 2020) [21]. Wheatgrass-incorporated products offer a cost-effective way to enhance nutritional value, as wheatgrass is relatively inexpensive to produce compared to other superfoods like spirulina or quinoa (Padalia *et al*., 2010) [16]. The scalability of these formulations is feasible, given the simplicity of incorporating wheatgrass powder into existing recipes for cookies, smoothies, and energy bars. However, challenges such as shelf-life stability, microbial safety, and cost optimization need further exploration. The increased moisture content in wheatgrass-incorporated products suggests the need for preservatives or modified packaging to prevent spoilage (Singh *et al*., 2012) [19].

The study also contributes to the broader discourse on superfood integration into mainstream diets. Unlike supplements, which may have limited consumer appeal, functional foods like those developed in this study can be seamlessly incorporated into daily consumption patterns, promoting long-term health benefits (Bigliardi & Galati, 2013) [4]. The 10% incorporation level identified as optimal provides a practical guideline for manufacturers aiming to balance nutrition and sensory appeal.

Limitations and Future Research

Despite the promising results, this study has limitations. The sensory evaluation was conducted with a semi-trained panel, which may not fully represent diverse consumer preferences. Future studies should involve larger, more diverse panels to validate acceptability across different demographics. The shelf-life stability of wheatgrass-incorporated products was not assessed, which is critical for commercial applications. Additionally, the long-term health impacts of consuming these products were not evaluated, necessitating clinical trials to confirm benefits such as improved antioxidant status or reduced disease risk (Bar-Sela *et al*., 2015).

Future research could explore alternative processing methods to enhance bioactive retention, such as vacuum drying or encapsulation of wheatgrass powder. Investigating the bioavailability of wheatgrass's bioactive compounds in these food matrices would further validate their functional food status. Additionally, incorporating wheatgrass into other food products, such as pasta, bread, or yogurt, could expand its applications and market reach.

Conclusion

This study successfully developed and evaluated wheatgrass powder-incorporated functional foods—cookies, smoothies, and energy bars—demonstrating their potential as nutrient-dense, health-promoting products. The incorporation of wheatgrass powder at 5%, 10%, and 15% significantly enhanced protein (up to 12.3%), fiber (up to 6.8%), and ash content, while boosting antioxidant activity (up to 78.4% DPPH inhibition) and total phenolic content (up to 350 mg GAE/100g). Sensory evaluation identified 10% incorporation as the optimal level, balancing nutritional benefits with consumer acceptability, particularly for cookies (7.8/9). These findings highlight wheatgrass's viability as a functional ingredient, offering a cost-effective strategy to address dietary deficiencies and oxidative stress-related health concerns. However, challenges such as sensory limitations at higher incorporation levels and potential shelf-life issues require further investigation. Future research should focus on optimizing formulations, assessing long-term health impacts, and exploring additional food matrices to broaden wheatgrass's applications. This study provides a foundation for the food industry to innovate and meet the growing demand for functional foods, promoting healthier dietary choices.

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