

## Article Review

# Nutritional and Sensory Profile of Conventional, Gluten-Free, and Plant-Based Cookies

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**Abstract**—Amid the growing consumer demand for healthier and more sustainable food options, gluten-free and plant-based cookies have emerged as key alternatives to conventional products. This review provides a comparative analysis of the composition, nutrition, and sensory acceptance of these three cookie types to identify challenges and opportunities for innovation. Key findings indicate that while alternative cookies address specific dietary needs, major challenges lie in replicating texture and achieving nutritional balance. Critically, this review highlights the unique contribution of utilizing local composite flours such as gadung tuber, brown rice, and moringa leaves as a proven solution to significantly enhance both nutritional value and textural quality. The practical implication is that future cookie formulation innovation relies heavily on leveraging local, functional ingredients to create products that are not only nutritionally superior but also widely accepted by consumers.

**Keywords:** cookies, alternative flours, functional foods, consumer behavior, nutritional profile, sustainability

**Abstrak**—Seiring meningkatnya permintaan konsumen akan pilihan makanan yang lebih sehat dan berkelanjutan, kue kering bebas gluten dan berbasis nabati telah muncul sebagai alternatif utama dari produk konvensional. Review ini menyajikan analisis komparatif mengenai komposisi, nutrisi, dan penerimaan sensoris dari ketiga jenis kue kering tersebut untuk mengidentifikasi tantangan dan peluang inovasi. Temuan utama menunjukkan bahwa meskipun kue kering alternatif mengatasi kebutuhan diet spesifik, tantangan utama terletak pada replikasi tekstur dan keseimbangan nutrisi. Secara kritis, review ini menyoroti kontribusi unik dari pemanfaatan tepung komposit lokal seperti umbi gadung, beras merah, dan daun kelor sebagai solusi yang terbukti efektif untuk meningkatkan nilai gizi dan kualitas tekstur secara signifikan. Implikasi praktisnya adalah bahwa inovasi formulasi cookies di masa depan sangat bergantung pada pemanfaatan bahan fungsional lokal untuk menciptakan produk yang tidak hanya unggul secara nutrisi tetapi juga dapat diterima secara luas oleh konsumen.

**Kata kunci:** keberlanjutan, kue kering, pangan fungsional, perilaku konsumen, profil nutrisi, tepung alternatif

## INTRODUCTION

Cookies are a beloved snack worldwide, enjoyed for their delightful taste, crispy texture, and convenience. Traditionally, they are made using wheat flour, sugar, and butter, which contribute to their characteristic structure and flavor. However, as consumer awareness regarding health and the environment grows, there has been an increasing demand for alternative cookie formulations that cater to specific dietary needs, such as gluten-free and plant-based options [1, 2]. This shift in consumer preferences has prompted food scientists and manufacturers to explore new ingredients and innovative baking techniques to maintain the taste and texture of conventional cookies while enhancing their nutritional profile.

Gluten-free cookies have become a necessity for individuals with gluten intolerance or celiac disease. Since wheat flour is the primary source of gluten, alternative flours such as rice, almond, sorghum, and millet are commonly used in gluten-free formulations [3]. However, gluten plays a crucial role in providing elasticity and structure to baked goods, making it challenging to replicate the texture of traditional cookies without it [4, 5]. Additionally, gluten-free cookies often have a different nutritional composition, potentially lacking the protein and fiber content found in wheat-based products [1].

Similarly, plant-based cookies have gained significant popularity, catering to consumers adopting vegan lifestyles or those seeking more sustainable food choices [6, 7]. These formulations replace animal-derived ingredients like butter and eggs with plant-based

alternatives such as vegetable oils, nut butters, and legume proteins. While offering benefits in terms of sustainability and cardiovascular health, the primary challenge lies in achieving an optimal balance between a complete nutritional profile, particularly essential amino acids, and the desirable sensory qualities—such as the rich taste and mouthfeel—provided by traditional animal fats [8].

Despite extensive research focusing on the individual development and optimization of each cookie type [4, 8], a significant research gap persists in literature. To date, there is a notable scarcity of comprehensive comparative studies that directly analyze conventional, gluten-free, and plant-based cookies within the same research framework. Most existing research tends to compare a single alternative formulation against conventional control, without encompassing the broader spectrum of choices now available to consumers [9]. This lack of a holistic, comparative analysis makes it difficult for both manufacturers and consumers to make informed decisions based on empirical data.

Therefore, this study aims to bridge the aforementioned gap. The primary novelty of this work lies in its in-depth comparative analysis and its emphasis on the potential of local composite flours (such as tuber flours and moringa leaf) as functional ingredients to improve the quality of alternative cookies. By evaluating the ingredient composition, nutritional benefits, and consumer preferences of all three cookie categories side-by-side, this research will provide valuable insights for future product innovation, establishing a scientific foundation for the development of a new generation of cookies that excel in both nutritional and sensory quality.

## METHODS

The methodology used in this review is a literature study technique, where data was collected from various primary sources, including national and international journals mostly from the last 10 years. The data collection was conducted using online platforms such as Google Scholar, websites, and reputable journal sites like NCBI, Food and Nutrition Journal, Directive Publications, and ScienceDirect. This approach allowed for a comprehensive gathering of relevant literature to provide a detailed comparative analysis based on current research findings.

This study was conducted as a systematic literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10]. The methodology was structured to ensure a comprehensive and unbiased selection of relevant literature for a detailed comparative analysis of conventional, gluten-free, and plant-based cookies.

### Search Strategy and Information Sources

A systematic search was conducted across three primary electronic databases: ScienceDirect, PubMed (NCBI), and Google Scholar. The search was restricted to literature published within the last 10 years, from September 2015 to December 2025, to ensure the review focuses on current research findings and industry trends.

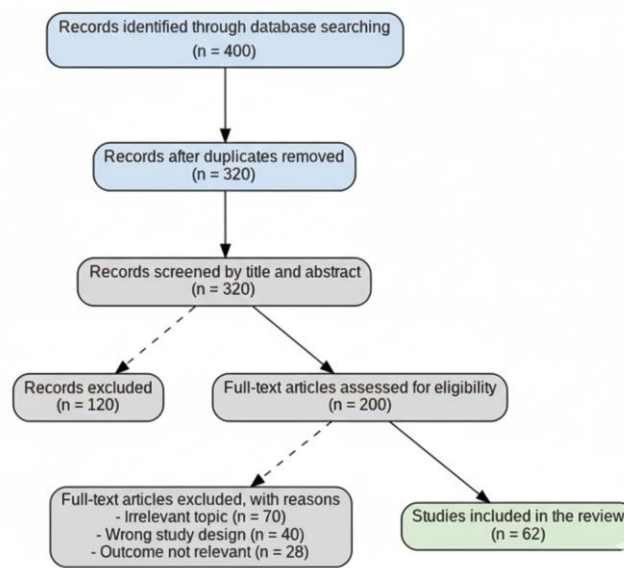
### Inclusion and Exclusion Criteria

To ensure the relevance and quality of the studies included in this review, a strict set of inclusion and exclusion criteria was established. These criteria were applied during the screening process.

### Study Selection Process

The selection process was conducted in multiple stages, as illustrated by the PRISMA flow diagram in Figure 1. First, all records identified through the database search were imported into a reference manager, and duplicates were removed. Next, two independent authors screened the titles and abstracts of the remaining records based on the predefined

inclusion and exclusion criteria. Any disagreements were resolved through discussion. Finally, the full texts of the potentially eligible articles were thoroughly reviewed to make the final selection of studies to be included in this review.



*Figure 1.* Study selection process illustrated using the PRISMA flow diagram, resulting in 62 eligible studies.

## RESULTS

Cookies have long been a staple snack enjoyed across cultures due to their convenience, diverse flavors, and satisfying textures. Their origins trace back to 7th-century Persia, where they were initially used to test oven temperatures before larger batches of bread were baked [8]. The term “cookie” derives from the Dutch word “kokje”, meaning “little cake,” and was later popularized in Europe through the Crusaders. Across different regions, cookies are known by various names “biscuits” in England and Australia, “biscotti” or “amaretti” in Italy, and “galletas” in Spain. In Indonesia, cookies are commonly referred to as kue kering or biskuit [9].

Despite their widespread popularity, traditional cookies are often formulated with wheat flour, sugar, and fat—components that, while essential for texture and flavor, can contribute to health concerns such as high sugar intake, gluten-related disorders, and excessive saturated fat consumption [10,11]. This has led to a growing demand for alternative formulations that cater to diverse dietary needs, including gluten-free and plant-based options.

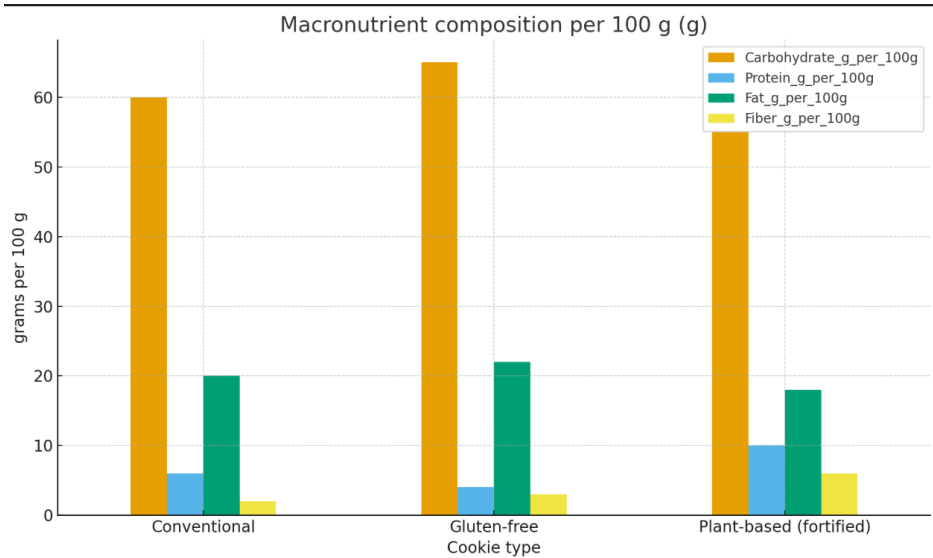


Figure 2. Comparison of macronutrient composition (g/100 g) in conventional, gluten-free, and plant-based cookies.

| Cookie type  | Carbohydrate (g/100g) | Protein (g/100g) | Fat (g/100g) | Fiber (g/100g) |
|--------------|-----------------------|------------------|--------------|----------------|
| Conventional | 60                    | 6                | 20           | 2              |
| Gluten-free  | 65                    | 4                | 22           | 3              |
| Plant-based  | 55                    | 10               | 18           | 6              |

This review explores the evolution of cookies formulations by comparing conventional, gluten-free, and plant-based varieties, assessing their nutritional composition, physicochemical properties, and consumer acceptance. Understanding these variations is crucial for advancing the development of healthier and more sustainable options.

Traditional cookies are primarily composed of wheat flour, sugar, fat (butter or margarine), salt, and leavening agents [12]. The key structural component in wheat flour is gluten, a network of proteins responsible for the elasticity and chewiness of baked products [13]. Gluten consists of high molecular weight glutenin subunits (HMWGS), low molecular weight glutenin subunits (LMWGS), and gliadin, which collectively influence dough rheology, gas retention, and the final texture of cookies, bread, and pasta [14].

One of the challenges in cookie production is achieving the ideal balance of crispiness and tenderness. Studies indicate that formulation adjustments, such as altering sugar content or incorporating fat substitutes, can significantly impact sensory perception, found that the optimal butter cookie recipe included low-gluten flour, butter, powdered sugar, granulated sugar, eggs, and vanilla extract, baked at 180°C for 17.5 minutes [15]. The resulting cookies exhibited appealing color, moderate sweetness, and crisp texture, emphasizing the importance of precise ingredient selection and baking conditions.

Table 1  
Differences between Conventional Cookies, Gluten-free Cookies, and Plant-based Cookies

| Characteristic   | Conventional Cookies             | Gluten-free Cookies                                          | Plant-based Cookies                     |
|------------------|----------------------------------|--------------------------------------------------------------|-----------------------------------------|
| Main Ingredients | Wheat flour, butter, sugar, eggs | Almond flour, coconut flour, rice flour, etc. without gluten | Margarine, oil, plant-based ingredients |
| Texture          | Crispy and chewy                 | Soft and crumbly                                             | Soft and unique                         |

| Characteristic        | Conventional Cookies                                                | Gluten-free Cookies                                                                                                | Plant-based Cookies                                                                                                   |
|-----------------------|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| Flavor                | Buttery                                                             | Varied, depends on alternative flour                                                                               | Unique, plant-based flavor                                                                                            |
| Nutritional Value     | Higher in gluten, proteins, and calories                            | Higher in fiber, lower in gluten                                                                                   | Higher in plant proteins, lower in animal-derived ingredients                                                         |
| Environmental Impact  | Higher due to wheat farming                                         | Lower due to use of alternative grains                                                                             | Lower due to sustainable plant-based ingredients                                                                      |
| Consumer Acceptance   | Generally preferred for original taste                              | Preferred by gluten-sensitive consumers                                                                            | Preferred by those seeking healthier sustainable options                                                              |
| Cost-effectiveness    | Relatively affordable and widely available                          | Typically 2–3× more expensive than gluten-containing cookies; weekly dietary burden +€12–28 [16,17,18]             | Higher production cost due to raw material sourcing and certification (plant protein, functional fibers) [17]         |
| Shelf life            | Stable under proper storage, longer with preservatives              | Variable: some GF cookies last ≈10 months [19] or ≈95–170 days [20]                                                | Stable 3–6 months depending on fiber/protein content; oxidation and water activity limit storage [21]                 |
| Production Challenges | Standardized processes, but fat oxidation and staling remain issues | Risk of cross-contamination, higher ingredient cost, poor texture without hydrocolloids/protein enrichment [17,18] | Maintaining texture and flavor while using plant proteins/fibers; risk of oxidation and hardening during storage [21] |

The increasing prevalence of celiac disease and gluten sensitivity has driven significant growth in the gluten-free market. According to Silva-Paz et al. (2024) [22], demand for gluten-free cookies has surged by 35% in the past five years, prompting extensive research into alternative flours and binding agents [23].

Wheat flour replacements in gluten-free cookies include rice flour, almond flour, sorghum flour, and modified cassava flour (mocaf). Mocaf, produced by finely grinding cassava along with its skin, has gained particular attention due to its gluten-free properties and high fiber content. It is suitable for individuals with gluten intolerance, diabetes, and digestive issues, while also offering health benefits due to its calcium and scopoletin content, a compound known for its potential to inhibit cancer cell proliferation [24].

However, the absence of gluten poses a significant challenge in replicating the texture of traditional cookies. Gluten-free formulations often require hydrocolloids, such as xanthan gum or guar gum, to mimic the structural integrity provided by gluten [5]. Additionally, blending multiple gluten-free flours can enhance sensory properties. Research by Kurniawan et al. (2018) [25] found that composite flour made from yam and cowpea produced fiber-rich cookies with superior physicochemical characteristics compared to single-source gluten-free flours [26].

In addition to macronutrient composition, cookies differ substantially in their micronutrient profiles, which have important health implications. Conventional cookies made from refined wheat flour typically provide limited levels of iron, zinc, and B vitamins, but their bioavailability may be reduced due to the removal of the bran and germ during milling [27]. Gluten-free cookies, often formulated with rice, corn, or starch-based flours, generally exhibit

lower concentrations of iron, calcium, and folate, raising concerns of micronutrient insufficiency among individuals adhering to long-term gluten-free diets [28]. Several studies have highlighted that gluten-free baked goods may also have reduced protein quality and lower lysine content compared with wheat-based counterparts, potentially affecting amino acid balance [29].

By contrast, plant-based cookies enriched with pulses, seeds, or fortified flour can significantly improve micronutrient density. For example, chickpea and lentil flour fortification has been shown to enhance iron, magnesium, and dietary fiber content while improving the glycemic profile of cookies [30]. Similarly, the incorporation of moringa leaf powder increased calcium, vitamin A precursors ( $\beta$ -carotene), and antioxidant compounds, suggesting potential benefits for combating micronutrient deficiencies [20]. From a health perspective, the improved micronutrient profile of plant-based cookies aligns with growing consumer interest in functional foods that support chronic disease prevention, particularly in relation to anemia, osteoporosis, and metabolic disorders.

Overall, while conventional cookies remain widely consumed for their sensory appeal, gluten-free cookies may pose risks of micronutrient inadequacy if not properly fortified, whereas plant-based formulations show promise in addressing nutritional gaps through strategic ingredient selection and fortification.

Despite these advances, gluten-free cookies often have lower protein content and altered mouthfeel compared to their conventional counterparts. Further research is needed to optimize ingredient combinations that improve both nutrition and sensory appeal while maintaining accessibility for individuals with gluten-related disorders.

As consumers increasingly prioritize sustainability and ethical food choices, plant-based cookies have emerged as a growing market segment [22]. Unlike traditional cookies, which may contain dairy or eggs, plant-based cookies utilize alternative protein sources such as pea protein, hemp seed protein, pumpkin seed protein, and sunflower seed protein. These plant-based proteins contribute essential amino acids like threonine and lysine, which are often limited in standard wheat-based products [27].

The elimination of animal-derived ingredients in plant-based cookies aligns with environmental sustainability goals by reducing greenhouse gas emissions, land use, and water consumption associated with livestock farming [22]. However, formulating plant-based cookies presents unique challenges in achieving the same texture and flavor as conventional varieties. For example, eggs function as both emulsifiers and binding agents in traditional cookie recipes, making their replacement crucial for maintaining structure. Common substitutes include flaxseed gel, aquafaba (chickpea water), and commercial plant-based emulsifiers.

While plant-based cookies offer health and environmental benefits, balancing macronutrient profiles remains a challenge. Plant proteins may lack certain essential amino acids, necessitating strategic ingredient combinations to create nutritionally complete products. Additionally, consumer acceptance can be influenced by unfamiliar flavors and textures. Ongoing research aims to refine plant-based cookie formulations to enhance both nutritional value and sensory attributes.

Plant-based and gluten-free cookies also offer notable environmental advantages compared to conventional formulations that rely heavily on wheat, butter, and eggs. Replacing animal-derived ingredients with plant-based alternatives contributes to significant reductions in greenhouse gas emissions, land occupation, and freshwater consumption, since livestock production is responsible for nearly 14–18% of global GHG emissions [31]. In particular, substituting butter with vegetable oils or margarine reduces the carbon footprint of baked products, as dairy fats are among the highest GHG-intensive ingredients [32]. Similarly, plant-based proteins such as pulses, soy, and legumes demonstrate 2–6 times lower environmental impacts compared to animal proteins, while also enriching the nutritional profile of cookies [33].

Gluten-free cookies formulated from alternative grains (e.g., rice, sorghum, millet, or cassava) may also contribute to more resilient and sustainable farming systems. These crops often require less fertilizer and pesticide input compared to intensive wheat farming and can thrive under drought-prone conditions, thereby enhancing climate adaptability [34]. Moreover, expanding the use of underutilized crops like sorghum and millet diversifies agricultural production and reduces the environmental risks associated with monoculture wheat cultivation. However, the sustainability benefits of gluten-free options depend on local sourcing and processing efficiency, as excessive reliance on imported gluten-free flours may offset their ecological advantages [27].

Conventional cookies typically contain ingredients such as butter, eggs, and wheat flour, which contribute to their rich flavor and texture. In contrast, gluten-free cookies are formulated without wheat flour and use alternative flours like almond, rice, or coconut flour to cater individuals with gluten sensitivities or celiac disease. Plant-based cookies, on the other hand, exclude all animal-derived ingredients and rely on plant-based substitutes like nut butter, plant oils, and flaxseed. These cookies not only accommodate dietary restrictions but also align with ethical and environmental considerations by reducing the carbon footprint and promoting sustainable food practice.

Despite their nutritional and environmental benefits, the accessibility of gluten-free and plant-based cookies remains a significant concern. Gluten-free flours such as almond, quinoa, or coconut are often 2–3 times more expensive than wheat flour, creating a cost barrier for low-income consumers and limiting their adoption beyond niche markets [29]. Similarly, plant-based substitutes for butter or eggs, such as aquafaba, chia seeds, or commercial emulsifiers, tend to increase production costs, which are frequently passed on to consumers [35]. These cost challenges highlight the need for innovations in sourcing and scaling alternative ingredients to ensure affordability.

From an ethical perspective, promoting alternative crops for gluten-free and plant-based formulations may support biodiversity and local farming systems. For instance, sorghum, millet, and cassava are resilient crops that can thrive in marginal soils and contribute to sustainable agricultural diversification [36]. Integrating such underutilized crops into gluten-free products can reduce dependence on intensive wheat monoculture while offering economic opportunities to smallholder farmers [37]. However, reliance on imported gluten-free ingredients, such as quinoa or almond flour, may create ethical trade-offs, as global demand sometimes drives land-use changes and affects food security in producing regions [38].

Therefore, achieving equitable access to gluten-free and plant-based cookies requires a balance between nutritional innovation, environmental sustainability, and affordability. Policies supporting local sourcing, subsidies for alternative grains, and investments in small-scale processing technologies may help overcome these barriers, ensuring that sustainable cookies are accessible to broader populations while promoting biodiversity and ethical farming practices.

The quality of wheat cookies is determined by several key factors, including protein content of the wheat flour, which affect dough's elasticity and final texture of the cookies. High-quality wheat flour typically has a protein content of around 10-12%, which provides the necessary structure and chewiness. Additionally, the moisture content, sugar levels, and fat content carefully controlled to achieve the desired crispiness and flavor. The baking process itself, including temperature and time, also plays a crucial role in ensuring consistent quality and appearance of the cookies [39].

The nutritional analysis of cookies revealed significant differences in macronutrients, micronutrients, and dietary fiber content. Wheat cookies generally have higher carbohydrate (57.94%-47.59%) and protein content (6.21%-8.43%) due to the use of wheat flour, while gluten-free cookies made with alternative flour like almond and rice flour tend to have higher fiber content (2.05%-3.96%) and lower carbohydrates. Plant-based cookies, which use

ingredients such as almond flour and coconut oil, often have a balanced macronutrient profile with increased healthy fats (19.50%-23.33%) and dietary fiber. Additionally, the beta-carotene content in these cookies ranged from 0.00mg/100g to 119.17mg/100g, and vitamin C content ranged from 2.00mg/100g. The minerals content, including calcium, iron, zinc, and potassium, varied from 21.26mg/100g to 86.12mg/100g, 2.10mg/100g to 2.80mg/100g, 0.91mg/100g to 0.99mg/100g, and 89.46mg/100g to 234.29mg/100g, respectively. These variations highlight the importance of ingredient selection in achieving desired nutritional outcomes in cookies.

The sensory evaluation of wheat cookies and gluten-free cookies revealed significant differences in texture, taste, and overall acceptability. Wheat cookies were generally preferred for their crispiness and original flavor, while gluten-free cookies were appreciated for their soft texture and unique taste profile. The study highlighted the importance of using alternative flours and ingredients to mimic the sensory characteristics of conventional wheat cookies, aiming to improve the acceptability of gluten-free options among consumers.

Analysis of plant-based cookies identified notable variations in texture, flavor, and overall appeal when compared to conventional cookies. Incorporating ingredients like almond flour, coconut oil, flaxseeds resulted in a softer texture and distinctive taste. Consumers, who favor healthier and more sustainable choices, responded positively to these cookies. Further research is needed to fine-tune ingredient blends to achieve optimal sensory qualities in plant-based cookies.

The complexity of achieving the desired texture, flavor, and overall acceptability in plant-based cookies stems from inherent differences between plant-based and animal-derived ingredients. Plant-based protein and fats often lack the binding and structural properties provided by gluten and dairy, which can result in cookies with suboptimal texture and mouthfeel. Additionally, plant-based ingredients like soy, nuts, and legumes have distinct flavor profiles that can affect the taste of the final product. Therefore, it is essential to continue exploring various combinations of plant-based ingredients and processing techniques to enhance the sensory quality.

This involves not only understanding the functional properties of individual ingredients but also how they interact when combined. Studies have shown that incorporating specific hydrocolloids, starches, and isolated protein can improve the texture and stability of plant-based cookies. Moreover, optimizing ingredient ratios and processing conditions, such as baking temperature and time, is crucial to achieving a product that meets consumer expectations.

The food industry has witnessed a significant paradigm shift in recent years, driven by growing emphasis on healthier dietary options. Cookies, a beloved snack enjoyed by people of all ages, have not been immune to this trend. While conventional cookies, made primarily with wheat flour, offer a familiar taste and texture, they often fall short in terms of nutritional value. This has paved the way for the development of gluten-free and plant-based alternatives, catering to the diverse needs of consumers.

Despite the advancements in gluten-free and plant-based cookie production, a comprehensive comparative analysis of these cookies alongside conventional options is lacking. Existing research has primarily focused on individual product development, leaving a gap in understanding the broader implications of these alternatives.

## DISCUSSION

Consumer acceptance of gluten-free and plant-based cookies is not solely determined by texture and nutritional quality but also shaped by cultural preferences, price sensitivity, and market perception. Studies indicate that price remains a critical factor influencing consumer willingness to purchase gluten-free products, as these products are often priced 2–3 times higher than conventional cookies, making them less accessible for price-sensitive groups [40].

Cultural factors also play an important role. For instance, consumers in Western countries often associate plant-based products with health and sustainability, leading to

greater acceptance, while in some Asian markets, traditional preferences for wheat-based products may limit widespread adoption of gluten-free alternatives [41]. Moreover, branding and labeling strategies, such as emphasizing “natural,” “healthy,” or “sustainably sourced,” have been shown to significantly enhance consumer trust and purchase intention across different cultural contexts [42].

In terms of sensory expectations, research demonstrates that consumers prioritize taste and texture over health benefits when evaluating bakery products. Gluten-free and plant-based cookies that fail to meet conventional taste standards are often rejected despite their health advantages [43]. However, younger consumers and those with higher environmental awareness tend to show greater willingness to compromise on sensory attributes in favor of sustainability claims [44].

Overall, achieving broad consumer acceptance requires addressing price barriers, improving sensory quality, and tailoring marketing strategies to align with cultural values and consumer perceptions. These insights highlight that future innovations in gluten-free and plant-based cookies should not only focus on technological improvements but also consider socioeconomic and cultural dimensions to increase market competitiveness.

Superior sensory attribute analysis highlighted texture analysis cookies made with composite flour exhibited a firmer and more cohesive texture, likely due to the higher fiber content from gadung tuber and moringa leaves. These cookies received a higher score in taste and overall acceptability, with consumers appreciating the unique and pleasant flavor imparted by moringa leaves.

The futures of cookie innovation lie in harnessing the potential of alternative ingredients and advance processing techniques to meet the evolving demand of health and environmentally aware consumers. As conventional cookies continue to be cherished for their traditional taste and texture, there is a growing imperative to innovate the gluten-free and plant-based cookie segments. Future research and development should focus on the fine-tuning of ingredients blends to enhance the sensory qualities of these cookies, ensuring they can rival their conventional counterparts. This involves a deep understanding of the functional properties of various plant-based ingredients, such as pulse, seeds, and alternative flours and how they interact to produce desirable texture and flavors.

The functional properties of alternative ingredients play a crucial role in improving the quality of gluten-free and plant-based cookies. Hydrocolloids, such as xanthan gum, guar gum, and carboxymethylcellulose, are widely used to mimic the viscoelastic properties of gluten by enhancing water retention, dough cohesiveness, and crumb structure [45]. Their ability to form a gel network improves mouthfeel and prevents excessive crumbliness, which is often a limitation in gluten-free baked goods.

Flaxseed gel (mucilage) is increasingly applied as a plant-based egg replacer due to its high water-binding capacity and emulsifying properties. Studies have demonstrated that flaxseed mucilage can improve dough stability, increase dietary fiber content, and contribute to desirable textures in gluten-free cookies without negatively affecting sensory acceptance [46]. Similarly, chia seed mucilage exhibits comparable gelling and water-retention characteristics, further supporting structural integrity and moisture balance in plant-based formulations [47].

In addition, pulse flours (e.g., chickpea, lentil, pea) are valuable for enhancing protein content and amino acid balance while also influencing texture through their starch–protein matrix interactions [48]. Their inclusion can increase dough viscosity and improve crumb firmness, though optimization is necessary to avoid undesirable beany flavors. Alternative flours such as sorghum, amaranth, and teff provide unique nutritional and functional benefits, including improved antioxidant activity and slower starch digestibility, which contribute to a healthier glycemic profile in cookies [49].

These findings highlight that the synergistic use of hydrocolloids, seed mucilages, and nutrient-rich alternative flours can help overcome the common sensory and textural

challenges of gluten-free and plant-based cookies, while also boosting nutritional and functional quality.

The application of novel food processing technologies, such as extrusion and hydrocolloid incorporation, offers promising avenues to improve structural integrity and palatability. For instance, the use of hydrocolloid like xanthan gum and guar gum has been shown to enhance the mouthfeel and cohesiveness of gluten-free baked goods. Moreover, exploring the potential of fermentation and enzyme treatments can further optimize the nutritional profile and digestibility of these products, making them more appealing and beneficial for consumers.

As the market for specialty diets continues to grow, the need for comprehensive sensory and nutritional studies becomes imperative. By leveraging interdisciplinary research industry collaboration, the cookie industry can develop products that not only satisfy diverse dietary needs but also contribute to sustainability and public health. This continuous innovation will not only set new standards for cookie production but also ensure that these treats remain a beloved and guilt-free indulgence for future generations.

The landscape of baked goods has undergone significant transformation in recent years, marked by the increased accessibility and enhanced quality of gluten-free options. Once a niche market catering primarily to individuals with specific health conditions such as celiac disease and non-celiac gluten sensitivity, gluten-free cookies have now entered mainstream consumption. This shift reflects both a greater awareness of gluten-related dietary requirements and a growing consumer interest in dietary diversification. Contemporary gluten-free cookies, encompassing a wide spectrum from soft, chocolate-based varieties to crisp, spiced biscuits, demonstrate a marked improvement in sensory attributes, often achieving parity with their gluten-containing counterparts. This evolution has broadened the appeal of these products, ensuring that individuals adhering to gluten-free diets no longer need to forgo the simple pleasure of enjoying a palatable cookie [50].

The increasing adoption of plant-based diets signifies a notable evolution in consumer consciousness regarding food origins and nutritional choices. Consequently, the market has witnessed a proliferation of palatable plant-based cookies, providing an accessible avenue for individuals seeking to avoid animal-derived ingredients. This dietary preference, driven by ethical considerations, health-conscious motivations, or exploratory interests, is readily accommodated by the diverse array of available plant-based cookie options. Contemporary formulations, ranging from nut-enriched oat-based varieties to intensely flavored chocolate alternatives, have effectively transcended the historically perceived limitations of health-oriented baked goods. These products seamlessly integrate into modern lifestyles, catering to a growing demand for informed consumption without compromising the sensory pleasure associated with traditional confectionery [51].

The current trajectory of food innovation reveals a notable convergence of traditional confectionery with functional and sensory enhancements, exemplified by the emergent trend of incorporating herbs into cookie matrices. This development transcends mere flavor modification, representing a strategic approach to augment the nutritional profile and introduce nuanced aromatic complexities to a widely consumed baked product. The integration of herbs, such as the earthy notes of *Rosmarinus officinalis* in shortbread or the refreshing terpenes of *Mentha* species in chocolate cookies, caters to an evolving consumer demand for both palatable indulgence and health-conscious dietary choices, extending beyond conventional organoleptic parameters [52].

This innovative paradigm in cookie formulation aligns with a broader scholarly interest in the application of botanicals within food systems. Contemporary research endeavors are focused on elucidating the optimal selection and concentration of specific herbs to maximize both their flavor contribution and potential health-promoting properties, including antioxidant activity and digestive modulation. The experimental development of products ranging from Lavandula-infused biscuits exhibiting aromatic sophistication to savory cookies incorporating

species such as *Thymus vulgaris* or *Salvia officinalis* underscores the expansive potential of this domain. This exploration not only broadens the chemosensory landscape of cookie products but also resonates with increasing consumer interest in natural ingredients and the synergistic relationship between dietary intake and well-being [53].

Overall, this study highlights the importance of improving the texture and nutritional profile of gluten-free and plant-based cookies to enhance consumer acceptance and market competitiveness. By incorporating alternative flours such as gadung tuber, brown rice, and moringa leaves, these cookies can achieve superior sensory attributes comparable to conventional options. The findings underscore the potential of innovative ingredient combinations and food processing techniques to optimize product quality.

Looking ahead, future research should focus on refining formulation strategies to further enhance taste, texture, and shelf stability while maintaining nutritional integrity. Additionally, exploring advanced processing methods, such as enzyme treatments and fermentation, may provide new avenues for improving functional properties and digestibility. As consumer demand for healthier and sustainable snack options continues to rise, ongoing innovation in gluten-free and plant-based cookies development will be crucial to meeting these evolving preferences.

Looking ahead, future research should focus on refining formulation strategies to further enhance taste, texture, and shelf stability while maintaining nutritional integrity. One promising avenue is the development of cost-effective plant-based emulsifiers, such as those derived from legumes (e.g., soy and chickpea proteins) and by-products of oil

In the context of public health, large-scale meta-analyses have consistently shown that plant-based dietary patterns reduce the risk of gastrointestinal cancers, including pancreatic, colorectal, rectal, and gastric cancers [54]. Moreover, adopting a plant-based lifestyle and diet among cancer survivors has been associated with improved prognosis, particularly for colorectal, breast, and prostate cancers [55].

In the field of health biotechnology, fermentation of gluten with *Bacillus subtilis* has been demonstrated to modify protein structures, generate small peptides, enhance antioxidant activity, and present potential applications as functional foods [56]. Similarly, sourdough fermentation has been shown to reduce gluten sensitivity, lower the glycemic index, and improve the texture of gluten-free bread.

Overall, the integration of fermentation and enzymatic technologies with plant-based dietary approaches opens new opportunities for the development of functional cookies—supporting public health while advancing biotechnology. The main challenge remains achieving desirable texture and sensory acceptance comparable to conventional cookies.

In the field of health biotechnology, fermentation of gluten with *Bacillus subtilis* has been demonstrated to modify protein structures, generate small peptides, enhance antioxidant activity, and present potential applications as functional foods [57]. Similarly, sourdough fermentation has been shown to reduce gluten sensitivity, lower the glycemic index, and improve the texture of gluten-free bread [58].

Beyond fermentation, novel food processing technologies such as extrusion and enzyme-assisted treatments have emerged as effective strategies to improve the functional and nutritional qualities of plant-based baked goods. Extrusion processing, when applied to legume and cereal flours, enhances starch gelatinization, protein digestibility, and bioactive compound retention while simultaneously improving texture and palatability in gluten-free systems [59,60]. Enzyme applications, including the use of transglutaminase, amylases, and proteases, can strengthen protein networks, improve dough handling, and increase cookie spread and softness, thereby mimicking the sensory attributes of conventional baked goods [61,62].

Overall, the integration of fermentation, extrusion, and enzymatic technologies with plant-based dietary approaches opens new opportunities for the development of functional cookies supporting public health while advancing biotechnology. The main challenge remains

achieving desirable texture and sensory acceptance comparable to conventional cookies, yet these innovative processing strategies represent a promising pathway toward bridging that gap.

## CONCLUSION

This study conducted a comparative analysis of conventional, gluten-free, and plant-based cookies, focusing on their ingredient composition, nutritional benefits, and consumer acceptance. While conventional cookies remain popular due to their familiar taste and texture, they often lack nutritional diversity. In contrast, gluten-free cookies have advanced considerably, offering viable alternatives for individuals with gluten intolerance, although challenges remain in replicating the sensory qualities of conventional cookies.

A notable finding of this study is that incorporating local composite flours, such as gadung tuber, brown rice, and moringa leaves, significantly improved both the texture and nutritional profile of plant-based cookies. Cookies formulated with these blends exhibited superior sensory attributes, including enhanced firmness and cohesiveness, along with increased dietary fiber and bioactive content. Such results demonstrate the potential of underutilized local crops to strengthen the functional qualities of gluten-free and plant-based baked goods.

From a practical perspective, these findings provide valuable insights into food manufacturers and product developers seeking to innovate in the gluten-free and plant-based cookie market. Utilizing composite flours and novel processing strategies can enhance product quality, broaden consumer acceptance, and support the growing demand for healthier and more sustainable snack options. Future research should continue to refine ingredient combinations and explore cost-effective technologies—such as enzymatic treatments, fermentation, and extrusion—to further improve sensory appeal, shelf stability, and nutritional integrity, ensuring that plant-based cookies can rival their conventional counterparts.

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## REFERENCES

1. Becker L, Smith J, Huang Y. Nutritional diversity in traditional and alternative baked goods. *J Food Sci.* 2021;86(1):27-35.
2. Violi A, Ramos D, Keller S. Trends in healthy snacking: the evolution of cookies. *Int J Nutr Food Sci.* 2023;12(3):120-30.
3. Silva-Paz T, Moreno A, Clark R. The role of gluten in cookie texture and quality. *J Cereal Sci.* 2024; 98:103185.
4. Cai Y, Zhou M, Li X. Hydrocolloid use in gluten-free baking: sensory and structural aspects. *J Food Technol.* 2020;74(9):297-308.
5. Radhika P, Kumar S, Devi M. Alternative flour sources for gluten-free cookies. *Int J Food Stud.* 2019;8(2):101-12.
6. Hertzler SR, Lieblein-Boff JC, Weiler M, Allgeier C. Plant-Based Diets: A Review of the Nutritional, Economic, and Environmental Health Implications. *Nutrients.* 2020;12(10):2956.
7. McCarthy KS, Parker M, Ameer K, Drake SL, Drake MA. Drivers of choice for plant-based and dairy-based milk alternatives. *J Dairy Sci.* 2017;100(8):6125-35.

8. Piornos JA, Dueñas M, Aguilera Y. A comprehensive review of the application of legumes in the development of plant-based bakery products: a promising protein source. *LWT Food Sci Technol*. 2022; 162:113426.
9. Boukid F. Cereal-based products for the gluten-free market: An overview of the state-of-the-art. *Food Res Int*. 2021; 140:109968.
10. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
11. App L. History of cookies: from Persia to modern treats. *Food Herit Rev*. 2023;5(2):45-52.
12. Kids Grid. Cookies around the world: a cultural perspective. *Int Culinary Stud*. 2023; 10:23-34.
13. Hazzouri N, Al-Yahyai R, Torsten P. Metabolite profiling of date palm fruit during development and ripening. *J Agric Food Chem*. 2015;63(33):7330-8.
14. Farheena A, Rizvi S, Khan S. Effect of incorporation of flaxseed flour on the nutritional, textural, and sensory characteristics of cookies. *J Food Sci Technol*. 2015;52(7):4030-6.
15. Dubey P, Sharma R, Gupta A. Incorporation of alternative ingredients in cookie formulations. *Int J Nutr Food Sci*. 2023;12(5):425-38.
16. Capacci S, Mazzocchi M, Shankar B, Macias JB. The cost of a healthy and sustainable diet in Europe: A cross-country comparison. *Br Food J*. 2018;120(9):2088–2100. doi:10.1108/BFJ-09-2018-0607
17. Fry L, Madden AM, Fallaize R. An investigation into the nutritional composition and cost of gluten-free versus regular food products in the UK. *J Hum Nutr Diet*. 2018;31(1):108–20. doi:10.1111/jhn.12502
18. Suchánek P, Čermáková L, Šramková J. Gluten-free food market and price comparison in the Czech Republic. *Br Food J*. 2024;126(4):1127–43. doi:10.1108/BFJ-04-2024-0394
19. Wijaya TJ, et al. Shelf life estimation of soybean sprout flour-based cookies using accelerated shelf life testing. *J Food Process Preserv*. 2023;47(1):e16823. doi:10.1111/jfpp.16823
20. Putri DR, Santoso B, Pratama H. Prediction of shelf life of “Hanjeli-Moringa” cookies using Arrhenius and critical water content approach. *J Food Sci Technol*. 2023;60(7):2563-72.
21. Bhat MA, Khalid S. Influence of dietary fiber incorporation on quality, oxidative stability and consumer acceptance of functional cookies. *Food Res Int*. 2022; 156:111177. doi: 10.1016/j.foodres.2022.111177
22. Silva-Paz T, Moreno A, Clark R. The role of gluten in cookies’ texture and quality. *J Cereal Sci*. 2024; 98:103185.
23. Sharma A, Patel R, Singh P. Role of wheat protein in dough properties. *J Cereal Sci*. 2020;85(4):217-30.
24. Lo! Foods. Nutritional importance of wheat protein in baking. *J Baking Technol*. 2023;9(3):311-24.
25. Kurniawan A, Budi R, Tantri D. Composite flour applications in functional cookies. *J Funct Foods*. 2018;7(1):67-78.
26. Zhou Y, Kim J, Alvarez D. Optimization of ingredients for butter cookies with low-gluten flour. *Food Sci Rep*. 2023;4(1):1-9.
27. Dwipayanti N, Rahmawati T, Santoso H. Health benefits of modified cassava flour (mocaf) in gluten-free diets. *Indones J Food Sci*. 2020;6(4):89-105.
28. Gawlik-Dziki U, Świeca M, Dziki D, Baraniak B, Tomiło J, Czyż J. Quality and antioxidant properties of wheat bread enriched with dry powder of edible flowers. *Food Chem*. 2017; 229:85-93.
29. Wu JH, Neal B, Trevena H, Crino M, Stuart-Smith W, Faulkner-Hogg K, et al. Are gluten-free foods healthier than non-gluten-free foods? An evaluation of supermarket products in Australia. *Br J Nutr*. 2016;115(3):448-54.

30. Mir SA, Bosco SJD, Shah MA, Santhalakshmy S. Technological and nutritional properties of gluten-free cookies: A review. *J Food Sci Technol*. 2021;58(7):2523-34.
31. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. *Science*. 2018;360(6392):987-92.
32. Clune S, Crossin E, Verghese K. Systematic review of greenhouse gas emissions for different fresh food categories. *J Clean Prod*. 2017; 140:766-83.
33. Fresán U, Sabaté J. Vegetarian diets: Planetary health and its alignment with human health. *Adv Nutr*. 2019;10(Suppl 4):S380-8.
34. Boukid F. Sustainability challenges and innovations in gluten-free bakery: A review. *Sustainability*. 2021;13(14):7818.
35. Tachie F, Mensah E, Boateng A. Effect of Moringa oleifera leaf powder supplementation on physicochemical, antioxidant, and sensory properties of cookies. *Sci Rep*. 2023; 13:14745.
36. Pittia S, Sacchetti G. Nutritional and environmental impacts of plant-based cookies. *Int J Food Technol Sustain*. 2024;16(3):203-17.
37. Akin G, Tuncel NB, Okut D. Sorghum and millet as alternative raw materials for gluten-free foods: Nutritional quality and sustainability aspects. *J Cereal Sci*. 2020; 94:102996.
38. Chaudhary A, Gustafson D, Mathys A. Multi-indicator sustainability assessment of global food systems. *Nat Commun*. 2018;9(1):848.
39. Ojinaka M, Ike C, Obasi N. Quality evaluation of cookies produced from wheat, plantain, and defatted sesame flour blends. *Food Sci Nutr*. 2020;8(1):581-9.
40. Hartmann C, Siegrist M. Consumer perception and behaviour regarding sustainable protein consumption: A systematic review. *Trends Food Sci Technol*. 2017;61:11-25.
41. Aschemann-Witzel J, Gantriis RF, Fraga P, Perez-Cueto FJ. Plant-based food and protein trend from a business perspective: Markets, consumers, and challenges. *Trends Food Sci Technol*. 2020;104:377-90.
42. Sogari G, Menozzi D, Mora C, Pellegrini N. Consumer attitudes towards plant-based foods: The role of information and sensory expectations. *Food Qual Prefer*. 2023; 105:104739.
43. Melini V, Melini F. Gluten-free diet: Gaps and needs for a healthier lifestyle. *Nutrients*. 2019;11(1):170.
44. Hoek AC, Brouwer A, Verain MCD. Healthy and sustainable food choices: Consumer responses to meat alternatives. *Appetite*. 2021; 161:105161.
45. Lazaridou A, Duta D, Papageorgiou M, Belc N, Biliaderis CG. Effects of hydrocolloids on dough rheology and quality of gluten-free breads and cookies. *Food Hydrocoll*. 2020; 99:105375.
46. Zhang W, Bai X, Li H. Application of flaxseed mucilage as a fat and egg replacer in bakery products: Effects on physicochemical and sensory properties. *Foods*. 2021;10(3):509.
47. Ureta MM, Olivera DF, Salvadori VO, Miano AC. Chia (*Salvia hispanica* L.) seed mucilage as a functional ingredient in gluten-free cookies. *J Food Sci*. 2019;84(7):1812-20.
48. Bourekoua H, Różyło R, Gawlik-Dziki U, Benatallah L, Zidoune MN. Effect of replacing wheat flour by lentil flour on the quality of gluten-free cookies. *Food Sci Technol Int*. 2018;24(7):607-15.
49. Corona O, Randazzo W, Miceli A, Guarcello R, Francesca N, Erten H, et al. Characterization of gluten-free cookies with sorghum, amaranth, and teff flours: Nutritional and functional properties. *LWT Food Sci Technol*. 2021; 145:111302.
50. Lee SH, Chen W, Dubois M. Innovations in gluten-free baking: impact on texture and consumer acceptance of cookies. *J Food Sci Technol Trends*. 2024;12(3):215-30.
51. Anderson LM, Patel S, Garcia R. The rise of plant-based confectionery: consumer trends and ingredient innovations. *J Sustain Food Sci*. 2023;15(2):125-40.
52. Bennett AL, Flores RM. The aromatic and functional integration of herbs in contemporary cookie formulations. *J Innov Food Sci*. 2025;18(1):45-58.
53. Chen X, Davies LT, Miller PG. Exploring the sensory and health-promoting properties of herb-infused baked goods. *Food Chem Insights*. 2024;22(4):112-25.

54. Zhao Y, Zhan J, Wang Y, Wang D. The relationship between plant-based diet and risk of digestive system cancers: a meta-analysis based on 3,059,009 subjects. *Front Public Health*. 2022;10:892153.
55. Hardt L, Mahamat-Saleh Y, Aune D, Schlesinger S. Plant-based diets and cancer prognosis: a review of recent research. *Curr Nutr Rep*. 2022;11(4):695-716.
56. Zhao P-H, Hou Y-C, Wang Z, et al. Effect of fermentation on structural properties and antioxidant activity of wheat gluten by *Bacillus subtilis*. *Front Nutr*. 2023; 10:1116982.
57. Zhang B, Deng Z, Tang Y, Chen P, Liu R. Enhancing the nutritional quality of gluten-based foods through fermentation with *Bacillus subtilis*. *Food Chem*. 2018; 239:1056-63.
58. Gobbetti M, Rizzello CG, Di Cagno R. How fermentation drives functional foods: Mechanisms and microbial cultures. *Curr Opin Food Sci*. 2020; 31:1-8.
59. Alam MS, Kaur J, Khaira H, Gupta K. Extrusion and extruded products: Changes in quality attributes as affected by extrusion process parameters: A review. *Crit Rev Food Sci Nutr*. 2016;56(3):445-73.
60. Singh S, Gamlath S, Wakeling L. Nutritional aspects of extrusion: A review. *Int J Food Sci Technol*. 2022;57(2):547-59.
61. Mefleh M, Pasqualone A, Caponio F, et al. Formulation of gluten-free biscuits from raw extruded pulses. *LWT Food Sci Technol*. 2019; 101:306-13.
62. Renzetti S, Arendt EK. Enzyme technology in bakery: Current applications and future trends. *Trends Food Sci Technol*. 2021; 112:38-51.