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Leveraging Pro-Vitamin A Cassava and Bambara Groundnut Composites: A Pathway to Combat Malnutrition and Reduce Wheat Dependency in Nigeria

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Abstract

Nigeria grapples with persistent protein-energy malnutrition and vitamin A deficiency, severely impacting millions, particularly vulnerable groups such as women and children under five. As the world's leading cassava producer, with an annual yield exceeding 54 million metric tons, Nigeria is uniquely positioned to harness biofortified pro-vitamin A cassava alongside the underutilized legume Bambara groundnut to develop nutrient-rich composite flours. This comprehensive review examines the nutritional synergy of these crops, their practical applications in value-added products like chin-chin, noodles, pasta, biscuits, and breads, and recent research from 2023 to 2025 that highlights significant improvements in protein (up to 61.7 g/kg), β-carotene (up to 91.39 μg/100g), fiber (up to 5.5 g/kg), and functional properties such as water absorption and swelling capacity. Drawing on empirical evidence, the study underscores how these composites reduce dependence on imported wheat, enhance food security, and address health challenges, while also offering economic benefits through rural income generation and environmental advantages via drought tolerance and nitrogen fixation. Challenges including Bambara groundnut's hard-to-cook trait, cassava's short shelf life, sensory issues at higher legume ratios, and processing constraints are analyzed, alongside scalable solutions. Recommendations include advanced research on blend optimization, pilot-scale production, long-term health assessments, and policy support for biofortification and market integration, positioning Nigeria to lead in sustainable, nutrition-focused agriculture.

Keywords: Pro-Vitamin A Cassava; Bambara Groundnut; Composite Flour; Malnutrition; Food Security; Nigeria; Biofortification

1. Introduction

In Nigeria, the persistent challenges of protein energy malnutrition and vitamin A deficiency represent a formidable public health crisis, exerting a profound impact on the well being of millions across the country and extending to over 25 million individuals throughout Africa and Asia. These nutritional deficiencies disproportionately affect vulnerable populations, particularly women and children under the age of five, who face heightened risks of stunted growth, impaired cognitive development, weakened immune responses, and increased mortality rates due to limited access to diverse and nutrient rich diets (De Moura et al., 2015; Saltzman et al., 2013). The root cause of these issues lies in the heavy reliance on staple crops such as cassava, which dominate daily meals and provide abundant carbohydrates, accounting for 64% to 72% of caloric intake in many households, but are critically deficient in essential proteins, vitamins, and minerals necessary for holistic health (Montagnac et al., 2009). This dietary imbalance is particularly acute in rural areas, where economic constraints and limited agricultural diversity exacerbate the problem, leaving large segments of the population nutritionally vulnerable.

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Nigeria's status as the world's leading producer of cassava, with an annual output surpassing 54 million metric tons, underscores its potential as a pivotal resource for innovative food security solutions (FAOSTAT, 2013). This abundant yield, cultivated across diverse agroecological zones, positions the country to leverage cassava as a foundation for addressing nutritional gaps. A significant breakthrough came with the introduction of biofortified pro vitamin A cassava in 2011, a genetically enhanced variety developed through conventional breeding to enrich its roots with β carotene, a precursor that the human body converts into vitamin A. This innovation delivers up to six times the vitamin A precursor levels found in traditional white fleshed cassava, offering a natural and sustainable strategy to combat the widespread vitamin A deficiency that contributes to blindness, immune suppression, and increased disease susceptibility among children (Aniedu and Omodamiro, 2012). The orange fleshed roots of this biofortified crop not only enhance nutritional value but also serve as a visible indicator of its health benefits, making it a promising candidate for dietary intervention.

To further amplify its nutritional impact, pro vitamin A cassava can be paired with Bambara groundnut, an indigenous legume renowned for its high protein content and ability to thrive in poor, nutrient depleted soils with minimal agricultural inputs. This complementary combination creates composite flours that can transform everyday foods, such as chin chin, a beloved West African snack traditionally crafted from imported wheat flour. Chin chin, with its crisp texture and widespread popularity, represents an ideal vehicle for introducing nutrient dense alternatives, reducing reliance on expensive wheat imports that burden Nigeria's trade balance and foreign exchange reserves (FAO, 2001). The integration of these local crops into familiar food products offers a culturally resonant approach to improving diets while supporting agricultural self-sufficiency.

The economic toll of wheat imports poses a significant challenge, draining national resources and contributing to trade imbalances that hinder economic stability, while the escalating effects of climate change, such as erratic rainfall, prolonged droughts, and soil degradation, further threaten agricultural productivity. These pressures necessitate innovative solutions that capitalize on indigenous crops adapted to local conditions. Recent research conducted between 2023 and 2025 has provided compelling evidence of the potential of pro vitamin A cassava and Bambara groundnut composites to mitigate these issues. Studies, including those by Oguntoye et al. (2025) and Uyanwa (2023), have demonstrated that these composite flours not only enhance nutritional profiles by increasing protein, β carotene, and micronutrient content but also improve functional properties such as water absorption and swelling capacity, making them viable substitutes for wheat in a range of products. This growing body of empirical work highlights the feasibility of scaling these innovations to address both health and economic challenges.

This article aims to provide a comprehensive review of the nutritional attributes of pro vitamin A cassava and Bambara groundnut, exploring their individual strengths and synergistic potential when combined into composite flours. It will delve into their practical applications across various food products, synthesize recent empirical findings from 2023 to 2025 that validate their efficacy, and assess the multifaceted benefits they offer, including nutritional, economic, and environmental advantages. Additionally, the review will address the challenges encountered in their adoption, such as processing constraints and sensory acceptance, and propose forward looking pathways that encompass research, policy support, and industry collaboration to integrate these crops into Nigeria's food system. By leveraging these underutilized resources, Nigeria has the opportunity to forge a resilient, nutrition focused agricultural future that aligns with both local needs and global sustainability goals.

2. Nutritional Profile of Pro-Vitamin A Cassava

Cassava, scientifically known as Manihot esculenta Crantz, stands as a cornerstone of Nigerian diets, revered for its remarkable drought tolerance that allows it to thrive in diverse agroecological zones, including arid and semi-arid regions where other crops struggle. This starchy root crop serves as a vital source of sustenance, providing essential carbohydrates that constitute 64% to 72% of its dry weight, primarily in the form of starch, alongside a modest amount of dietary fiber that supports digestive health (Westby, 2002). Its ability to yield consistent harvests under challenging climatic conditions has made it a dietary staple for millions, particularly in rural households where it is consumed in forms such as boiled roots, fufu, or garri. However, the traditional white-fleshed varieties of cassava are notably deficient in essential proteins and critical micronutrients, offering only about 1% to 2% protein content and minimal levels of vitamins and minerals. This nutritional gap contributes significantly to widespread health issues, including stunted growth, weakened immune systems, and increased susceptibility to infections among children and pregnant women, perpetuating cycles of malnutrition in vulnerable communities (Aniedu and Omodamiro, 2012).

The introduction of pro-vitamin A cassava marks a pivotal advancement in addressing these deficiencies through biofortification, a process that genetically enhances the crop to enrich its roots with β-carotene, a precursor that the human body converts into vitamin A. This biofortified variant, developed through conventional breeding techniques, can deliver up to six times the vitamin A precursor levels found in conventional cassava, offering a natural and sustainable solution to combat vitamin A deficiency, a public health concern affecting over 25 million people in Africa and Asia (Charles et al., 2005). The orange-fleshed roots of pro-vitamin A cassava not only provide a visually distinct marker of its nutritional value but also contribute to daily vitamin A intake, with recent evaluations demonstrating its efficacy in boosting serum retinol levels among preschool children in regions like Akwa-Ibom, Nigeria, where dietary diversity is limited (De Moura et al., 2015). This improvement is particularly crucial for young children, whose rapid growth and development depend on adequate vitamin A to support vision, immune function, and cellular health.

Despite these nutritional advancements, pro-vitamin A cassava retains certain limitations that necessitate complementary strategies to maximize its dietary impact. The protein content remains low, typically ranging from 1% to 2% on a dry weight basis, which is insufficient to meet the protein-energy needs of growing populations, especially when cassava dominates the diet. Additionally, the presence of cyanogenic glycosides—naturally occurring compounds that release toxic hydrogen cyanide—poses a safety concern if not properly managed, requiring meticulous processing to detoxify the roots and render them safe for consumption (Montagnac et al., 2009). To overcome these shortcomings, blending pro-vitamin A cassava with protein-rich crops like legumes becomes essential to create a more balanced nutritional profile. The processing of cassava into flour involves a series of labor-intensive steps, including peeling to remove the outer skin where cyanogens concentrate, grating to break down the root structure, pressing to expel moisture and toxins, drying to halt enzymatic activity, and milling into a fine powder. These methods effectively reduce cyanogenic content to safe levels, typically below 10 parts per million, while preserving the β-carotene and carbohydrate content, making the flour suitable for use in a wide range of products such as pastries, breads, and snacks (Garcia et al., 2012).

Emerging research further expands the potential of pro-vitamin A cassava by exploring its integration into innovative food formulations. Studies focusing on antioxidant-enhanced breads have incorporated cassava flour at levels around 10% of the total mix, combined with spices like ginger at 3%, to elevate phenolic content, which contributes to the bread's antioxidant capacity and shelf life stability (Robinson and Tas, 2025). These findings highlight additional health benefits, such as reduced oxidative stress, though the studies have not yet explored direct blending with legumes like Bambara groundnut. The increased phenolic levels suggest that cassava can serve as a functional ingredient beyond its traditional role, potentially enhancing the nutritional quality of baked goods when paired with complementary flavors and nutrients. This evolving research underscores the versatility of pro-vitamin A cassava, positioning it as a foundational component in the development of fortified foods that address both micronutrient deficiencies and consumer preferences for healthier options.

3. Nutritional Profile of Bambara Groundnut

Bambara groundnut, scientifically classified as Vigna subterranea, is a resilient and underutilized legume native to West Africa, frequently referred to as a "famine crop" due to its historical role as a fallback food source during periods of scarcity. This legume thrives exceptionally well in semi-arid zones, where its deep root system and ability to fix nitrogen enable it to flourish with minimal water, fertilizer, and other agricultural inputs, making it an ideal crop for marginal lands across the region (Linnemann and Azam-Ali, 1993). Its adaptability to harsh environmental conditions, including poor soils and unpredictable rainfall, positions it as a valuable asset for food security in climates increasingly affected by drought. Despite its potential, Bambara groundnut remains largely overlooked in commercial agriculture, with its cultivation predominantly confined to smallholder farmers who rely on traditional methods to sustain local food supplies (Odeniran O. M. 2025).

Nutritionally, Bambara groundnut stands out as a powerhouse, offering an average protein content of 19% on a dry weight basis, which surpasses many common legumes and provides a critical source of plant-based protein in regions where animal protein is scarce. This protein is particularly rich in essential amino acids, including methionine and lysine, which are often limiting in cereal-based diets and play vital roles in muscle development, immune function, and metabolic processes. In addition to its protein content, Bambara groundnut contains approximately 6.5% oil, contributing healthy fats that enhance energy density and palatability in prepared foods. The legume also provides significant amounts of dietary fiber, which supports digestive health and helps regulate blood sugar levels, alongside resistant starch that acts as a prebiotic to promote gut microbiota balance (Ihekoronye and Ngoddy, 1985; Brough et al., 1993). This well-rounded nutritional profile makes Bambara groundnut an ideal complement to starchy crops like cassava, which lack sufficient protein and micronutrients, thereby enhancing the overall nutritional balance of composite diets and addressing deficiencies such as protein-energy malnutrition prevalent in West Africa.

However, the presence of anti-nutritional factors poses a challenge to its full utilization, necessitating careful processing to unlock its nutritional potential. Compounds such as tannins, which can bind to proteins and reduce their digestibility, and trypsin inhibitors, which interfere with protein digestion in the gut, are naturally present in Bambara groundnut seeds. These factors can diminish nutrient bioavailability if left unaddressed, but heat processing methods such as boiling, roasting, or steaming effectively mitigate their effects by denaturing these compounds, rendering the legume safer and more digestible (Poulter, 1981). Recent scientific reviews have further explored its versatility, particularly in the production of extruded snacks, where blends with grains like pearl millet have demonstrated exceptional nutritional outcomes. These blends achieve protein levels as high as 20% and maintain low anti-nutrient concentrations through optimized extrusion conditions, offering a high-protein, shelf-stable snack option that appeals to both nutritional and commercial interests (Adeola et al., 2024).

In Nigeria, the cultivation of Bambara groundnut is predominantly a subsistence activity carried out by smallholder farmers, with a significant proportion being women who manage its growth alongside other household duties. These farmers rely on the crop for home consumption, using it in traditional dishes like porridges and soups, yet its commercial value remains largely untapped due to limited processing infrastructure, market access, and awareness of its nutritional benefits (Baudoin and Mergeai, 2001). The legume's potential to contribute to rural economies is immense, as its resilience and nutritional quality could support value-added products such as flours, snacks, and fortified foods, provided there is investment in training, equipment, and market linkages. The involvement of women in its production offers a unique opportunity to empower this demographic through cooperatives or microenterprises, enhancing their economic independence and contributing to gender equity in agriculture. Despite its current underutilization, Bambara groundnut's rich nutritional profile and adaptability position it as a promising candidate for scaling up production and integrating into modern food systems, particularly when paired with crops like pro-vitamin A cassava to address multifaceted dietary needs.

4. Applications in Composite Flours

The development of composite flours derived from pro-vitamin A cassava and Bambara groundnut presents a transformative opportunity to create gluten-free alternatives for a diverse array of food products, including traditional snacks like chin-chin, as well as noodles, pasta, biscuits, and other baked goods. Chin-chin, a widely cherished West African snack resembling a crisp doughnut with a firm texture, is conventionally prepared using wheat flour, which relies heavily on imports that strain Nigeria's economy and trade balance (FAO, 2001). By substituting wheat with blends of pro-vitamin A cassava and Bambara groundnut flours, this dependency can be significantly reduced, promoting self-sufficiency and supporting local agriculture. The production process begins with carefully blending the two flours in varying ratios, ranging from 90% cassava and 10% Bambara to 50% cassava and 50% Bambara, depending on the desired nutritional and sensory outcomes. This is followed by the incorporation of additional ingredients such as eggs for binding, margarine for richness, sugar for sweetness, and sometimes leavening agents, before the mixture is shaped, cut, and subjected to either frying for a golden, crispy finish or baking for a lighter texture, as outlined by Akubor (2004). These methods allow for flexibility in production, catering to both traditional preferences and modern dietary needs.

The functional properties of these composite flours undergo notable improvements as the proportions of cassava and Bambara are adjusted, enhancing their suitability for various culinary applications. Water absorption capacity, a critical factor for dough formation and texture, ranges from 75 to 87 grams per gram of flour, indicating the blends' ability to retain moisture effectively during processing and cooking. Oil absorption capacity, which influences the richness and mouthfeel of fried products, varies between 70 and 76 grams per gram, ensuring a balanced fat uptake that prevents greasiness. Additionally, swelling capacity reaches a peak of 8.47% at the 50:50 ratio, a property that contributes to the expansion and structural integrity of baked goods like biscuits and chin-chin, facilitating a desirable crispness or chewiness depending on the preparation method (Akintola and Anifowose, 2025). These enhanced functional attributes make the composites versatile for industrial-scale production, where consistency and quality are paramount.

Proximate analyses further reveal the nutritional superiority of these blends over traditional wheat-based flours. The protein content, a key nutritional enhancement provided by Bambara groundnut, ranges from 3% in lower Bambara ratios to 16% in higher blends, offering a significant boost to address protein-energy malnutrition. Fat content, influenced by the oil-rich nature of Bambara, spans from 21% to 24%, adding energy density and palatability to the products. The β-carotene content, sourced from pro-vitamin A cassava, varies between 47 and 91 micrograms per 100 grams, providing a vital source of vitamin A precursors to combat deficiency, particularly among vulnerable populations (Uyanwa, 2023). These nutritional gains position the composites as a health-promoting alternative, aligning with global efforts to improve dietary quality through biofortification.

Sensory evaluations play a crucial role in determining consumer acceptance, and studies indicate that blends up to a 60% cassava and 40% Bambara ratio are well-received by panels for their taste, texture, and overall appeal. This acceptability stems from the balance achieved between the mild, starchy flavor of cassava and the nutty undertones of

Bambara, which mimic the familiar profile of wheat-based products. However, adjustments may be necessary at higher Bambara ratios to refine flavor profiles, such as incorporating natural flavor enhancers like vanilla or spices, or modifying processing techniques to reduce beany notes and improve mouthfeel, as suggested by Oguntoye et al. (2025). These adaptations ensure that the sensory experience aligns with consumer expectations, facilitating market entry and encouraging widespread adoption. The combination of nutritional enhancement, functional versatility, and sensory optimization underscores the potential of these composite flours to revolutionize food production, offering a sustainable and locally sourced solution to Nigeria's dietary and economic challenges.

5. Recent Studies and Findings

Over the past few years, spanning 2023 to 2025, a growing body of research has provided robust validation for the practical applications of pro-vitamin A cassava and Bambara groundnut composites across a variety of food products, reinforcing their potential as viable alternatives to traditional wheat-based ingredients. One standout study by Oguntoye et al. (2025) focused on the development of gluten-free pasta, utilizing an optimal blend ratio of 60% pro-vitamin A cassava flour and 40% Bambara groundnut flour. This formulation yielded impressive nutritional enhancements, with protein content rising to 61.7 grams per kilogram and dietary fiber increasing to 5.5 grams per kilogram, significantly improving the nutritional profile compared to wheat pasta. The pasta also achieved high sensory scores for attributes such as taste, texture, and overall acceptability, as evaluated by trained panels, indicating strong consumer appeal. Cooking yield reached an exceptional 233%, reflecting excellent water absorption and retention during preparation, while experiencing a moderate weight loss of approximately 10% due to starch leaching, a level deemed acceptable for industrial production. These results position the pasta as a competitive wheat alternative, particularly for individuals with gluten intolerance, and highlight the potential for scaling this product in both domestic and international markets.

Another significant contribution comes from Uyanwa (2023), who concentrated on the formulation of cookies using the same 60:40 cassava-to-Bambara blend. The study reported a substantial protein content of 16.33%, coupled with a β-carotene concentration of 91.39 micrograms per 100 grams, underscoring the blend's ability to deliver essential nutrients critical for combating vitamin A deficiency. In-vitro digestibility was measured at an efficient 81%, indicating that the nutrients are readily bioavailable, while anti-nutrient levels remained within safe thresholds following appropriate processing techniques such as heat treatment and soaking. Sensory evaluations conducted with diverse panels revealed a preference for moderate Bambara inclusion, with the 60:40 ratio striking an optimal balance between nutritional benefits and palatable taste and texture. This preference suggests that consumer education and gradual introduction of higher legume ratios could further enhance acceptance, paving the way for broader market penetration of these fortified cookies.

Research into noodle production has also yielded valuable insights, with an optimal blend of 70% cassava flour, 43% Bambara groundnut flour, and a minor adjustment to 29.57% Bambara to fine-tune the mix, as documented in a recent but undated study published in the Journal of Food Quality. This formulation resulted in a protein content of 10.5 grams per 100 grams and an increase in antioxidant activity, attributed to the synergistic effects of the two crops' bioactive compounds. However, the study noted sensory declines at higher Bambara levels, with textures becoming overly firm and flavors shifting toward pronounced legume notes, which may require masking agents or flavor adjustments to align with consumer expectations. Meanwhile, Akintola and Anifowose (2025) explored the functional properties of these composites, particularly in extrusion processes, and identified that a 50:50 cassava-to-Bambara ratio achieved peak swelling capacity, a critical factor for producing uniform, well-textured extruded snacks and cereals. This finding enhances the versatility of the blends for industrial applications, offering manufacturers a reliable foundation for developing diverse extruded products with consistent quality.

Broader applications of these composites extend to baked goods, as demonstrated by Robinson and Tas (2025), who incorporated 10% cassava flour and 3% ginger powder into bread formulations. This combination not only boosted phenolic content, enhancing the bread's antioxidant properties, but also maintained its quality in terms of crumb structure, volume, and shelf life, appealing to health-conscious consumers. These findings build on earlier research by integrating modern optimization techniques, such as desirability functions, which allow researchers to systematically evaluate multiple response variables—like nutritional content, sensory appeal, and processing efficiency—simultaneously. This approach has refined the development process, ensuring that new products meet both nutritional and market-driven criteria. Collectively, these studies from 2023 to 2025 illustrate a progressive evolution in the utilization of pro-vitamin A cassava and Bambara groundnut composites, aligning with earlier foundational work while pushing the boundaries of innovation through advanced scientific methodologies and practical applications.

6. Economic and Environmental Benefits

Beyond their substantial nutritional advantages, the adoption of pro-vitamin A cassava and Bambara groundnut composites offers profound economic and environmental benefits that enhance sustainability and resilience in Nigeria's agricultural landscape. One of the most significant economic advantages lies in the reduction of wheat imports, a costly dependency that drains foreign exchange reserves and exacerbates trade deficits. By substituting imported wheat flour with locally produced composite flours, Nigeria can redirect substantial financial resources toward strengthening domestic agricultural systems. This shift not only conserves national wealth but also stimulates local economies by creating new opportunities for farmers, processors, and small businesses. A key beneficiary of this transition is the empowerment of women, who form a significant portion of the workforce cultivating Bambara groundnut in rural areas. Their increased involvement in growing, processing, and marketing these crops can lead to improved household incomes, enhanced social status, and greater access to education and healthcare, aligning with gender equity goals in agricultural development (Baudoin and Mergeai, 2001). Furthermore, the establishment of cooperative networks and training programs can equip these women with the skills and resources needed to scale their operations, fostering a more inclusive agricultural sector.

From an environmental perspective, the inherent characteristics of pro-vitamin A cassava and Bambara groundnut make them ideal crops for sustainable farming practices, particularly in the face of climate change. Cassava's remarkable drought tolerance allows it to thrive in regions with erratic rainfall, reducing water dependency and ensuring consistent yields even during prolonged dry spells. This resilience is critical in Nigeria's savanna zones, where water scarcity increasingly threatens traditional crops. Similarly, Bambara groundnut's nitrogen-fixing capability enriches the soil by converting atmospheric nitrogen into compounds that enhance fertility, thereby decreasing the reliance on synthetic fertilizers that contribute to soil degradation and greenhouse gas emissions (Linnemann and Azam-Ali, 1993). This natural soil enrichment not only lowers production costs for farmers but also promotes long-term land health, supporting crop rotation systems that prevent erosion and maintain biodiversity. The reduced need for chemical inputs further minimizes environmental pollution, aligning with global efforts to combat climate change and promote eco-friendly agriculture. Additionally, the localized production of these composites reduces the carbon footprint associated with long-distance wheat transportation, offering a greener alternative that supports Nigeria's contribution to international sustainability targets.

Economically, the development of value-added products derived from these composites presents a transformative opportunity to uplift rural communities and stabilize the national economy. Fortified snacks such as chin-chin, noodles, biscuits, and extruded products can be produced using the composite flours, tapping into both domestic and potential export markets. These products not only enhance nutritional intake but also generate additional revenue streams for rural households by creating demand for locally processed goods. The production of such items can stimulate agro-processing industries, providing employment opportunities for youth and women while reducing post-harvest losses that often plague cassava and Bambara groundnut farmers. Moreover, by cutting reliance on imported wheat, Nigeria can mitigate trade deficits, which have been a persistent economic challenge, and reinvest savings into infrastructure, research, and extension services to further bolster agricultural productivity (FAO, 2001). Recent innovations in food technology have underscored this potential, with extruded snacks made from Bambara blends demonstrating impressive commercial viability. These snacks, developed through advanced processing techniques, achieve high yields with low input costs, offering a scalable model that could be adapted for other composite products, thereby enhancing economic returns and market competitiveness (Adeola et al., 2024). This synergy of economic growth and environmental stewardship positions Nigeria to lead in sustainable food systems, balancing profitability with ecological preservation.

Challenges and Future Directions

Despite the promising nutritional and sustainability benefits of pro-vitamin A cassava and Bambara groundnut composites, several significant challenges must be addressed to facilitate their widespread adoption and commercialization. One primary obstacle is the inherent hard to cook trait of Bambara groundnut, which stems from its dense seed coat and high levels of anti-nutritional factors such as tannins and trypsin inhibitors. This characteristic requires extended cooking times, often 3 to 4 hours of boiling, to soften the seeds, leading to higher energy consumption and increased processing costs, particularly in resource-limited rural settings where fuel and equipment may be scarce (Brough et al., 1993). Additionally, improper processing can leave residual anti-nutrients, potentially reducing nutrient bioavailability and posing mild health risks if not mitigated through methods like soaking, germination, or fermentation. For cassava, the short shelf life of fresh roots, typically deteriorating within 24 to 48 hours post harvest due to high moisture content and enzymatic browning, complicates storage and transportation, necessitating rapid processing into flour to prevent spoilage and economic losses. This urgency can strain small scale processors, who may lack access to drying facilities or preservatives, further elevating costs and reducing efficiency. The presence of cyanogenic glycosides in cassava adds another layer of complexity, as inadequate detoxification during peeling, grating, pressing, and drying can result in toxic residues, requiring strict quality controls that may not be feasible in informal processing environments.

Sensory and functional challenges also hinder consumer acceptance and product development. At higher legume ratios in composites (e.g., beyond 40% Bambara groundnut), the blends often exhibit altered textures, such as increased hardness or grittiness, and off flavors like beany notes, which can deter consumers accustomed to wheat based products (Oguntoye et al., 2025). Functional properties, including lower water binding capacity and swelling power in some blends, may affect the dough handling, baking stability, and final product quality, making it difficult to achieve the desired crispiness in snacks like chin-chin or the elasticity in noodles. These issues are compounded by variability in raw material quality, influenced by factors like soil conditions, harvest timing, and varietal differences, which can lead to inconsistent outcomes in large scale production. Moreover, market barriers such as limited awareness among consumers and processors, coupled with inadequate infrastructure for value added processing, restrict the scalability of these composites, potentially limiting their impact on food security.

To overcome these hurdles and unlock the full potential of these crops, future research directions should prioritize multifaceted approaches. Optimization of blend formulations could be advanced through sophisticated experimental designs, such as response surface methodology or mixture process models, to fine tune ratios that balance nutritional enhancement with improved functional and sensory attributes. Pilot scale studies are essential to test these optimized blends in real world settings, evaluating processing efficiency, cost effectiveness, and shelf-life extension techniques like modified atmosphere packaging or natural preservatives. Long term health impact assessments, including randomized controlled trials on vulnerable populations, would provide robust evidence of the composites' efficacy in reducing micronutrient deficiencies, tracking biomarkers for vitamin A, iron, and protein status over extended periods. Additionally, breeding programs could focus on developing improved varieties of Bambara groundnut with reduced hard to cook traits and enhanced drought resistance, while integrating genomic tools to accelerate trait selection in pro-vitamin A cassava.

On the policy front, enhanced support for biofortification programs is crucial to integrate these crops into national strategies, including subsidies for seed distribution, training for farmers on best practices, and incentives for processors to adopt biofortified varieties (Saltzman et al., 2013). Collaborations between government agencies, research institutions, and private sectors could facilitate the mainstreaming of composites into school feeding programs, public procurement systems, and export markets, ensuring equitable access and economic viability. By addressing these research and policy priorities, Nigeria can transform these underutilized crops into cornerstones of a resilient, nutrition focused food system.

7. Conclusion

The integration of pro-vitamin A cassava and Bambara groundnut composites emerges as a highly practical and multifaceted solution to address Nigeria's entrenched nutritional and economic challenges, offering a transformative approach to revolutionize dietary habits and agricultural practices nationwide. These often-overlooked crops hold immense potential, with recent studies from 2023 to 2025 providing robust evidence of their efficacy, demonstrating substantial enhancements in dietary quality through increased protein content reaching 61.7 g/kg, β-carotene levels up to 91.39 µg/100g, and fiber up to 5.5 g/kg, alongside improved functional properties like a 233% cooking yield for pasta and peak swelling at 50:50 ratios. This nutritional uplift effectively combats the pervasive issues of protein-energy malnutrition and vitamin A deficiency, fostering overall health resilience, especially among vulnerable populations such as women and children under five who are disproportionately affected.

Economically, the adoption of these composite flours presents a strategic pathway to diminish Nigeria's heavy reliance on imported wheat, a significant drain on foreign exchange reserves and a persistent threat to trade balance stability. By substituting locally sourced and processed flours, the nation can redirect financial resources to strengthen domestic agriculture, creating new income opportunities for rural communities and empowering smallholder farmers, many of whom are women cultivating Bambara groundnut in savanna regions. This shift promotes self-reliance, stimulates local economies, and supports gender equity through enhanced access to education, healthcare, and economic independence via cooperative networks and training programs.

Environmentally, the inherent adaptability of pro-vitamin A cassava and Bambara groundnut to climate change challenges is a critical asset. Cassava's exceptional drought tolerance ensures consistent yields in water-scarce areas, while Bambara groundnut's nitrogen-fixing capability enriches soil fertility, reducing the need for synthetic fertilizers and mitigating soil degradation and greenhouse gas emissions. This sustainability enhances long-term agricultural viability, supports resilient farming systems against erratic weather, and lowers the carbon footprint associated with wheat importation, aligning with global eco-friendly goals and positioning Nigeria as a pioneer in sustainable food innovation.

Realizing this potential, however, requires overcoming substantial hurdles. The processing challenges, such as Bambara groundnut's hard-to-cook nature necessitating extended cooking times and cassava's short shelf-life demanding rapid processing, call for investment in affordable, scalable technologies to ensure consistent quality and accessibility. Sensory acceptability issues at higher Bambara ratios, marked by altered textures and off-flavors, may necessitate flavor enhancements or texture refinements, while market barriers like limited awareness and inadequate infrastructure pose scalability constraints. These obstacles are surmountable through targeted research and development efforts focused on optimizing formulations, improving processing efficiency, and extending shelf life with techniques like modified atmosphere packaging.

The path forward relies on collaborative action. Policymakers must prioritize funding for biofortification programs, subsidies for seed distribution, and training initiatives to integrate these crops into national food security and agricultural development strategies. Researchers should expand on current findings with large-scale field trials to refine composite ratios, assess long-term nutritional impacts through randomized controlled trials, and develop cost-effective processing methods. Industry stakeholders can drive progress by investing in value-added products such as fortified chin-chin, noodles, biscuits, and extruded snacks, appealing to diverse markets. By embracing these "forgotten" crops, Nigeria can construct a healthier, more resilient food system that meets the nutritional needs of its population, secures economic stability, and promotes environmental sustainability. This transformation demands a concerted effort to shift cultural perceptions, upgrade agricultural infrastructure, and foster public-private partnerships, ultimately elevating pro-vitamin A cassava and Bambara groundnut from subsistence crops to mainstream staples. Such a shift could inspire a nourished, self-reliant Nigeria, serving as a powerful model for other nations in the global south facing similar challenges.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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