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REVIEW

Harnessing indigenous agro-processed flour blends as composite bioresources in functional food development

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Abstract

Flours from inexpensive but perishable indigenous crops like cereals, legumes, roots, and tubers contribute about 90% of food calories intake worldwide. These can be processed as composites and prepared into readily available wholesome staple functional food products possessing multiple functions that provide some physiological, therapeutic, and nutritional benefits. This development entails blending flours from various plant sources (in different percentages) to produce a variety of food products. Their macronutrients compositions and diverse array of secondary metabolites associated with enhanced bioactive potentials can be annexed together to obtain balanced diets necessary for survival and confer substantial health benefits in preventing and managing chronic diseases. For an adult diet therapy to be accepted as healthy, it generally should averagely be able to provide calories daily in the following proportions: carbohydrates (55%), protein (22.5%) and fat (27.5%). This can be achieved using flour blends of most indigenous botanicals. The interest in producing functional food commodities from mixed flour is increasing globally and is currently captivating researchers' curiosities. With lots of raw botanicals of comparative advantage and heavy post-harvest losses, African countries like Nigeria could use this technology to enhance the utilization of their agricultural bio-resources. These flour blend developments will accelerate the exploitation of native food crops toward producing ready-to-eat, highly nutritious functional food products like bread, cakes, and biscuits. This review highlights the nutritional quality, value, and health derivatives obtained from using underutilized plant materials as composite flour to prepare ready-to-eat bakery and staple functional food products. Diet therapy is a formidable means of prolonging life expectancy, as eating right and healthy can be a significant strategy in boosting immunity in this post-COVID-19 era.

1. Introduction

Food is an essential ingredient of life; it is fundamental to nourish the body with appropriate diets in supplementary rations to promote a healthful and helpful lifestyle (Butnariu and Sarac, 2019). Functional foods are beneficial food constituents that are instrumental to the overall healthiness of the body by delivering and equipping the body with rudimentary nutritional fortifications, which helps in essentially boosting the body's immunity while cutting down on the likelihood of contracting some diseases. Such foods include fruits, grains, vegetables, beverages, and some nutritional supplements (Chen *et al*., 2021). Various conventional foods with functional attributes are still being discovered, examined, and developed into beneficial new food products. Consumers can choose helpful foods and beverages that can enhance their health and nutritional status when they know the food ingredients can impact specific health benefits (Galanakis *et al.,* 2020; John and Singla, 2021).

The technological concept of blending foods into composite functional foods forms was conceived in 1964 by the Food and Agricultural Organization (FAO) as an economic strategy to encourage non-wheat growing member nations in using their home-grown food crops of comparative advantage as fragmentary substitutes to wheat flour, thereby reducing the cost of acquiring wheat from majorly temperate wheat-growing countries

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(Hasmadi *et al.,* 2020). Many developing countries in sub-Saharan Africa, like Nigeria, encourage the introduction of schemes to access the practicability of using comparatively advantaged indigenous crop flours as an alternative for wheat flour (Ohizua *et al.,* 2017; Adeyeye, 2018). This can further be developed into different composite functional food products.

According to the FAO (2022) report on the state of food security and nutrition globally, 11 million individuals die yearly due to unhealthy dieting, while 828 million persons (almost 10% of the world's human population) were estimated to be faced with hunger in 2021. This is a quantum leap by as much as 46 million and 150 million from the 2020 and 2019 estimates, respectively. Also, FAO (2021) reported that the number of persons who could not access adequate food in 2020 was nearly 2.37 billion (up by 320 million persons in 2019). These grim statistics has led to some agencies of the United Nations Organization (UNO) like FAO, World Health Organization (WHO) and World Food Program (WFP) to warn of a "looming catastrophe" as world hunger levels steadily rises year-on year (Y-O-Y) after the COVID-19 pandemic. With the threatening effects of the global climatic variations coupled with various armed conflicts (especially the Russian-Ukraine warfare leading to massive destruction, destabilization, migration and more), starvation and famine is estimated in an unrivalled dimension owing to hike in food, fertilizer and fuel prices particularly in developing African countries. This is possible because Russia and Ukraine rank third and fourth largest global grains exporters respectively and Russia is also a prominent exporter of fertilizer and fuel (FAO, 2022). No country in the world is currently exempted from this; hence, various attempts to obliterate malnutrition in all its ramifications through vital nutritional and dietary remediation are proving difficult. The continuously high levels of poverty and income inequality and the high cost of procuring healthy diets have continually kept rich, healthy diets out of reach of around 3 billion people worldwide. This situation can be alleviated by using composite functional foods from indigenous flours obtained from raw botanicals reserved in each region of the world without recourse to importation.

The interest in functional foods development and production has become more heightened among research scientists due to the various red flag warnings raised by some multi-national governing bodies like (FAO) and (WHO) about unhealthy diet consumption induced by lifestyle practice, leading to chronic diseases (FAO, 2021a). The devastating widespread effect of COVID-19 on national economies has made enhancing immunity and initiating avenues of developing accessible low-end healthy diets crucial to humans. Therefore, the consumption of rich-healthy diets is an option available to human end-users to boost immunity (Rowan and Galanakis, 2020).

Several authors have defined composite flour used in bakery and pastry as either two or more innovative blends of flours, starches, and different ingredients from some other crops (in different percentages) to replace wheat flour entirely or partly to yield economically standard unique quality functional food product varieties (Butnariu and Sarac, 2019). A mixture of flours is often obtained from home-grown cereals, legumes, fruits and starch-rich tubers (such as potatoes, yam, carrots, cassava and more) to ensure that the basic relevant nutritional features are justifiably present. Composite functional food products will provide a balanced nutrient that delivers better dietary benefits and nutritional value because they contain more proteins, minerals, fibres, nutrients, and vitamins in their combinations, much more than when a particular crop flour is milled and used alone (Adeyeye, 2018).

Generally, composite food technology is an excellent way of creating distinctively novel food products from the combinations of conventional and unconventional botanicals. These composite flour developments will accelerate the further exploitation of native food crops toward producing ready-to-eat, highly nutritious functional foods such as bread, cakes, and biscuits. The nutritional quality and value and health derivatives obtained from using unseemly, underutilized plant materials as composite blends/food mixes in the preparation of ready-to-eat bakery and pastry staple food products cannot be over-emphasized.

Over the years, wheat has been used as an essential part of flour blends because of customers' preference, high availability, extensive acceptability and ease of production technique. Some of the positive effects of supplementing wheat flour with inexpensive composite flour staples are observed in the finished products concerning improvements made on the nutritional quality, functional and physicochemical properties, health value of the raw flour blends, and the proportions used, as well as its overall acceptance on different types of food products (Galanakis, 2021).

Since wheat has always been the gold standard in the bakery and pastry industries, it is expected that the composite flour-based foods produced should have attributes as similar as possible to the standards obtained from whole-wheat floured products. The outcome of the formulation used in any composite flour preparation should possess comparable features or qualities to whole -wheat flour products. Such quality characteristics, like

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having better nutrient content and general outlook, should be like products obtained when wheat flour is used. Still, their texture and properties are entirely away from wheat flour products (Ohizua *et al.,* 2017).

Although wheat has exceptional caloric and nutritional content, when compared with other grains in terms of its protein constitutions, it does not have enough amounts of some necessary amino acids like lysine and threonine (Siddiqi *et al.,* 2020; Poutanen *et al.,* 2022). Also, the abdominal immune disorder called celiac disease has been linked to the continual consumption of wheat-based diets among wheat intolerant persons (Kiin-Kabari and Giami, 2015). These concerns have made it imperative to incorporate composite blends into the processing of various wheat-based products.

Developing composite functional foods from raw botanicals in developing countries will help preserve their earned foreign currency reserve by reducing/eliminating importation of wheat flour in the bread and pastry sector, boosts and promotes the utilization of indigenously prolific locally grown crops as flour, provide an alternative means of essential macro and micronutrients necessary for human life, increase public health benefits, drastically reduce post-harvest losses and improves the entire agricultural food value chain while contributing appreciably to the Gross Domestic Product (GDP) of the country's economy (Yuliana *et al*., 2018; Hasmadi *et al.,* 2020). These advantages will help to solve the triple problems of food wastage, malnutrition and low Gross Domestic Products (GDP). This is possible because indigenous composite botanicals are economical to harvest, easy to process into flour, store and transport, do not deteriorate readily if preserved dry, and are enriched with macro and micronutrient sources. Consuming a high amount of it has significantly decreased the risk of many diseases (Sedigheh *et al*., 2017; Galanakis *et al*., 2020). Various researchers have carried out studies showing that composite flour combinations from different crops as primary raw materials could be used as viable alternatives adequately relevant in functional food product preparations (Adeola and Ohizua, 2018; Adeyeye, 2018; Adejuwon *et al*., 2021).

There is a paradigm shift in the direction of functional foods development; researchers in composite food technology are not only looking for enhanced bioactivity in food combinations using various food processing techniques but also currently concentrating their efforts on reutilizing the by-products from these hitherto undesirable food waste, thereby protecting the environment (Torres-León *et al*., 2018; Galanakis, 2021). If overcome, this current food industry challenge will deliver to man and its economy, a bioresource-effective, environmentally sustainable foods containing tremendous health-boosting nutrients over commercially available artificial food additives (Galanakis, 2020). The attention of food research scientists to focus on this area is justified. The GDP of African economies will be exponentially boosted if these untapped comparatively advantaged crops/bio-resources are properly annexed into composite functional food products. It could deliver extra, supplementary, and better-refined bio-functional nutrients for the human body than just mere gastronomical delectation if well harnessed.

This review, therefore, is aimed at improving the bioeconomy and contributes to the food and nutrition security of developing nations with a view of attaining sustainable development goal (SDG) number two. It highlights the nutritional quality-potentials, economic value as well as health derivatives obtained from the possibility of using comparatively advantaged locally available botanicals, by harnessing their flour blends potentials as agro-processed composite bio-resources in developing ready-to-eat bakery and pastry staple functional food products.

2. Improving bio-economy using composite flour blends

African countries blessed with numerous raw botanicals (Table 1), can develop appropriate technological know-how to improve its bio-economy by utilizing the capacity of its autochthonous agricultural bio-resources in developing composite flours across the continent especially in areas where wheat supply falls short. The current local cultivation of wheat in most African countries is grossly inadequate, for example in Nigeria, in spite of government interventions in this sub-sector, current wheat production capacity is less than 5% of its annual needs, it has barely increased from 7,000 tonnes in 1971 to 110,000 tonnes for the 2022 marketing year (Essiet, 2021; Mojeed, 2022) (Figure 1).

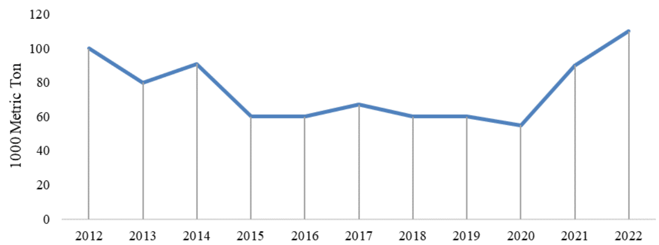

Figure 1. Wheat production for Nigeria from 2015-2022. Source: Essiet (2021) and Mojeed (2022).

Cultivation occurs mainly in thirteen Northern states (Adamawa, Bauchi, Bornu, Gombe, Jigawa, Kaduna, Kano, Kastina, Kebbi, Plateau, Sokoto, Yobe and Zamfara states) majority of these states are currently enmeshed in various degrees of insecurity that hinders

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Table 1. African raw botanicals of comparative advantage.

S/N	Category	Agricultural Produce	[a]African Countries	[b]Production Capacity (%)	References
1.	Grains	Maize/corn (*Zea mays*)	Nigeria, Egypt, Ethiopia, Tanzania	7.5	International Institute of Tropical Agriculture (2018).
2.		Wheat (*Triticum aestivum*)	Ethiopia, South Africa, Sudan, Kenya, Tanzania	20.6	International Food for Agricultural Development (IFAD), 2016
3.		Sorghum (*Sorghum bicolor*)	Nigeria, Ethiopia, Sudan, Burkina Faso, Niger,	44.15	FAO (2020).
4.		Millet (*Pennisetum glaucum* and *Eleusine coracana*)	Nigeria, Niger, Burkina Faso, Mali, Senegal	29.23	Food and Agriculture Organization of the United Nations, Statistics Division (FAOSTAT) (2017).
5.		Rice (*Oryza sativa*)	Nigeria, Egypt, Madagascar, Tanzania.	3.4	FAOSTAT (2020)
6.	Roots and Tubers	Potato (*Solanum tuberosum*)	Egypt, Ethiopia, Kenya, Nigeria, Uganda	7.12	FAOSTAT Yearbook (2021)
7.		Yam (*Dioscorea spp*)	Nigeria, Ghana, Ivory Coast, Benin, Ethiopia	94	FAOSTAT (2020).
8.		Sweet potato (*Ipomoea batatas*)	Nigeria, Uganda, Ethiopia, Tanzania	30.50	FAO (2020)
9.		Sugar Cane (*Saccharum officinarum*)	South Africa, Sudan, Kenya, Swaziland, Mauritius	1.95	FAO (2019)
10.		Cassava (*Manihot esculenta*)	Nigeria, Ghana, Tanzania, Congo	64	FAOSTAT Yearbook (2021)
11.	Fruit and Vegetables	Banana (*Musa paradisiac*)	Angola, Uganda, Cameroon, Ghana, Tanzania.	21	FAOSTAT (2018)
12.		Garlic (*Allium sativum*)	Egypt, Algeria, Ethiopia, South Africa.	2.67	FAOSTAT (2020)
13.		Ginger (*Zingiber officinale*)	Nigeria, Cameroon, Mali, Ethiopia, Ivory Coast.	15.2	FAOSTAT Yearbook (2021)
14.		Kola Seed (*Cola acuminata*)	Nigeria, Ivory Coast, Cameroon, Ghana, Sierra Leone	56.6	Onaolapo and Onaolapo, (2019); FAOSTAT (2020)
15		Pawpaw/Papaya (*Carica papaya*)	Ghana, Nigeria, Angola, Algeria	9.7	FAO (2020)
16		Pepper (*Capsicuma annium*)	Madagascar, Ethiopia, Ghana, Rwanda	50.0	FAOSTAT (2020)
17		Bitter kola (*Garcinia kola*)	Nigeria, Ivory Coast, Cameroon, Ghana, Sierra Leone	85	FAO (2019)
18		Orange (Citrus sinensis)	Egypt, South Africa, Morocco	4.06	FAOSTAT (2020)
19	Pulse/ Legumes	Bean (*Phaseolus vulgaris*)	Tanzania, Uganda, Kenya, Nigeria, Burkina Faso	25	FAOSTAT (2020)
20		Groundnut (*Arachis hypogea*)	Nigeria, Sudan, Chad, Cameroon, Senegal	24	FAOSTAT (2021)
21		Pigeon Pea (*Cajanus cajan*)	Malawi, Kenya, Tanzania	16.1	FAO (2018)

[a]Top three to five African countries producing each commodity.
[b]Percentage annual production capacity from the African continent alone.

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farmers from accessing farmlands. The massive improvement in wheat cultivation from 55,000 tonnes in 2020 to 110,000 tonnes in 2022 has been attributed to the diversification efforts of the previous government (Mojeed, 2022). With its 2023 human population estimated at over 223.81 million and projected to rise beyond 400 million by the year 2050 (Worldometers.info, 2023), all that has been done to meet rising wheat demand is importation which has steadily been rising over the years, with an average annual growth rate of 11.83% (Figure 2). In order to overcome this massive demand and supply gap, it is estimated that the Central Bank of Nigeria (CBN) spends over USD 2billion of its nation's scarce foreign resources annually importing wheat (Odifa, 2023).

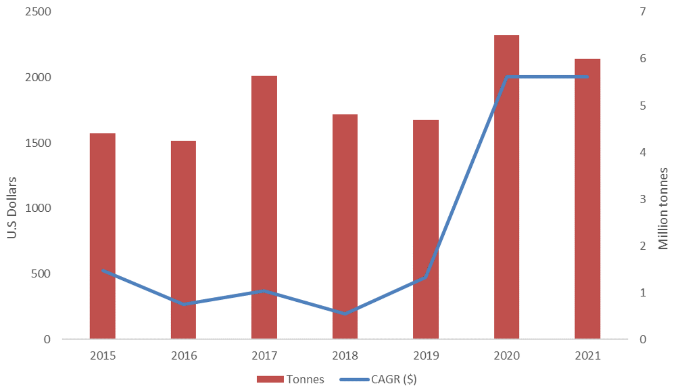

Figure 2. Wheat imports for Nigeria from 2015-2021. Source: Essiet (2021) and Mojeed (2022).

The increase in population growth to wheat demand is attributed to usage by manufacturers in producing wheat-based food products such as flour, pasta, semolina, noodles, and wheat meal. The size of the Nigerian biscuit industry is estimated at 121 billion naira (over USD 294 million), with a common annual growth rate (CAGR) of 16% in the last five years (Essiet, 2021). Developing a home-grown solution by harnessing and processing available agricultural bio-resources into flour blends to produce functional food products that would feed the 14.6% of its undernourished population will create much-needed jobs, improve the GDP for the entire agricultural value chain, incorporates all crops of comparative advantage and minimize heavy post-harvest losses.

The agricultural sector has become the backbone of most developing economies by creating job opportunities for more than 70% of its population (GAIN report, 2019), the Nigerian government as well as other relevant stakeholders in Africa with lots of raw botanical sources but heavy post-harvest losses should embrace this technology more to enhance its bioeconomy, thereby increasing the agricultural food value chain for baked foods and pasta.

3. Nutritive quality and value of composite functional foods

Functional foods are foods enriched and fortified with ingredients already present in them, containing various biologically active compounds like peptides, antioxidants, and lipids, which, when consumed, confers optimal maintenance to the overall health status of an individual (Nikolova *et al.*, 2018; Galanakis, 2021). The biologically active compounds essential for human nutrition are made up of intrinsic food constituents that positively impact the body's effectiveness with immune boosters suitable for its continuous well-being (Galanakis *et al.*, 2020). Some functional foods have been traditionally consumed for their health benefits and have proven to be very effective (Chiba *et al.*, 2017).

The nutritional value of these foods can be adequately improved upon by using such processing techniques as roasting, boiling, germination, and fermentation (Rollán *et al.*, 2019; Voidarou *et al.*, 2021). Roasting helps to meliorate sensorial properties and preserve the nutritive content of majority of minerals and vitamins in foods, but its prolong cooking period at elevated temperatures could influence the B-group vitamins negatively (Schlörmann *et al.*, 2020). Germination, a highly amenable but viable non-chemical procedure commonly used to promote the availability of significant bionutrients, has been reported to boost the nutritional value of legumes and grains by activating or producing various endogenous enzymes (Nkhata *et al.*, 2018; Anaemene and Fadupin, 2020; Al-Ansi *et al.*, 2022). Boiling which is a fast and simple culinary method requiring intense heating and a substantial amount of water, often decrease the bioactive phytochemical metabolites in vegetable foods, removes water-dissolving and heat-susceptible vitamins like Vitamin C by up to 50% or more and minerals by 60-70% in some food materials. Leafy vegetables have been completely leached out when steeped in hot water (Lee *et al.*, 2018). Fermentation (bio-processing technology) use microorganisms and their enzymes to convert food nutrients into distinct fermented food products, improving food nutritional quality by breaking down the nutrients and making them easier to digest than their unfermented forms (Nkhata *et al.*, 2018; Rollán *et al.*, 2019; Voidarou *et al.*, 2021). These products act as natural preservatives with distinct appearance, texture, taste and aroma. It alters the intestinal micro flora balance by promoting good food digestibility, enhancing bio-accessibility of essential nutrients, inhibiting the growth of harmful bacteria thereby, increasing resistance to infections, boosting immune functions and probiotic activities (Nkhata *et al.*, 2018; Rezac *et al.*, 2018; Kwofie *et al.*, 2020; Adejuwon *et al.*, 2021). As antiquated as fermentation is in food preservation, it is

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still being used in producing a variety of fermented foods, beverage and dairy products (Tamang *et al.*, 2019; Gopikrishna *et al.*, 2021; Voidarou *et al*., 2021).

Functional microorganisms modify the physical and chemical compositions of their original food material sources during fermentation, enhancing both probiotic potentials and the nutrient's bioavailability, boosting sensory features of the food, influencing bio-preservatives (antioxidant, peptides produced and antimicrobial) activity while enhancing safety and reducing noxious constituents of such foods (Sharma *et al.,* 2020; Voidarou *et al*., 2021).

Most of the Bacteria isolated from fermented foods and beverages have been predominantly identified as lactic acid bacteria (LAB) such as *Lactobacillus, Lactococcus, Leuconostoc, Pediococcus, Streptococcus, Weissella* and *Enterococcus* (Mokoena, 2017; Sharma *et al.,* 2020). For fungi (yeasts and moulds), *Saccharomyces, Mucor, Debaryomyces, Penicillium, Geotrichium, Rhizopus, Kluyveromyces* and *Geotrichium* species (Kwofie *et al.*, 2020). A detailed compendium of different types of functional microorganisms in fermented foods universally, can be obtained from Tamang *et al.* (2015).

During processing under ideal situations, the overall metabolic potentials of these functional microorganisms are fully expressed using their enzyme systems to disintegrate compounded biomolecules to their simpler forms used in performing various biologic functions. For example, *Bacillus* spp. has produced catalase, amylase, proteinase, mannose and cellulose that have been used to develop functionally viable fermented Soybean foods in various countries in Asia (Tamang *et al*., 2016).

All functional food products from composite blends will furnish us with significant nutrients in the portion needed by our body for a balanced diet, maturation, and general well-being. These blends provide exceptional micro and macro nutritive combinations compounded from carbohydrates, vitamins, roughages, proteins, and essential minerals like Iron, calcium, and potassium (Galanakis, 2021). According to the National Academy of Sciences Macronutrients Dietary Reference Intakes (2006), for an adult diet therapy to be acceptable as healthy and balanced, it generally should be able to provide a nutritive value that contains carbohydrates (45-65%), fat (20-35%) and protein (10-35%), this can be achieved with composite blends of most indigenous African botanicals (Ohizua *et al.,* 2017; Adeyeye, 2018).

Some essential vitamins (such as vitamin B, riboflavin, Thiamine and niacin) cannot be made by our bodies in sufficient amounts that it needs; our diets supply these nutrients. Niacin, essentially produced by living cells from tryptophan, is naturally present in and obtained from various green vegetables and cereals diets. Body tissues absorb niacin by transforming it into its metabolically effective derivative, a coenzyme also known as nicotinamide adenine dinucleotide (NAD). Thiamine functions as a water-soluble vitamin by helping to break down carbohydrate foods into energy-producing sugars. Most breakfast cereals, beans, and sunflower seeds are rich in Thiamine. Riboflavin, widely obtained from various plants and animal foods (such as nuts, green vegetables, enriched flours, milk, eggs, and meat), is essential for generating the energy needed for the body's proper functionality (Rowan and Galanakis, 2020).

For the mineral component of composite foods, Calcium is necessary for continual bone health, that is, the formation and preservation of good healthful bones. Iron helps in transporting oxygen to the cells where it is used. Potassium facilitates the acquisition of the correct fluid mixture balance that cells require to work correctly (Galanakis, 2021). The Isoflavones constituents in soybean are known to prevent various diseases (Ouis and Hariri, 2018), while the polyphenols are very efficacious antioxidants necessary to fend off the uncontrolled build-up of the body's free radicals. They can be obtained from vegetables, green tea, and fresh fruits (Chiba *et al.*, 2017).

Dietary fibre comprises a mixture of different constituents that confers rigidity to the cell wall structure. It makes digestion of various foods pass more quickly through our digestion system, thereby minimizing the effect of some common bodily disorders such as constipation (Adeola and Ohizua, 2018). In the large intestine, anaerobic bacteria ferment various precursors from dietary fibre, protein, glycoprotein, polysaccharides, peptide, resistant starch, and oligosaccharides yielding metabolic Short-chain fatty acids (SCFA) (Cione *et al*., 2021).

The conjecture that proper nourishment is one of the essential features responsible for a person's overall healthy outlook, especially in the COVID 19 pandemic era, has been scientifically proven (Galanakis, 2020; Rowan and Galanakis, 2020). During the pandemic, bioactive components in functional foods have been suggested to reinforce immunity against COVID-19 disease (Galanakis *et al.*, 2020; Galanakis, 2021). The modern consumer has begun looking for alternatives and is now developing a fondness for natural products and their constituents inherent in foods instead of relying on synthetically combined drugs. They now choose to acquire their desired health benefits from their diet and

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not from medical remedies since the awareness of nutrition science is that "man is what he eats." Consumers now believe that minimally processed foods have better health benefits than processed ones. A broad range of fermented foods is available for today's consumers' delight (Nakai *et al*., 2017; Galanakis, 2021).

Using better processing and manufacturing technology, functional food components are being scrutinized as food additives to strengthen food products' health claims (Galanakis, 2021). Functional food products can also be varied by adding different valued ingredients. The increasing number of composites in functional food products used in the bakery and pastry industries is goading a growing amount of other developmental research surveys on the physiochemical and functional effects on various kinds of materials used for these products since composite's functional properties have an essential part in the production of functional foods (Ohizua *et al.,* 2017; Adeyeye, 2018; Adejuwon *et al*., 2021). Before functional food products can be effectively deployed commercially, it is necessary to adopt an all-around strategy involving inter-connected components performing a similar activity in practical food development. The exercise should begin with consideration and analyzing product conceptualization, key focus areas concerning the regulatory situation, labelling and others. Further action to be carried out is the chemical elucidation of the biologically active constituents necessary for providing the needed and wholesome health effects (Galanakis, 2021).

The critical roles of some functional foods and their bioactive compounds in terms of their nutritional benefits and the prevention of diseases have increased the development of the functional food market (Chiba *et al*., 2017; Rahimian *et al*., 2018; Galanakis *et al*., 2020). The past decade has seen the functional food markets in developed countries progressively yielding over USD$8 billion and USD$21.3 billion to Europe and the United States, respectively (Kobayoshi *et al*., 2017; Galanakis, 2020). The expansion in the functional foods sector can also be attributed to additional facets like improved quality of older people's life, regular rise in longevity, and the cost of Medicare. This is why global policymakers are initiating steps to encourage and expand functional food products (Galanakis, 2020).

4. Health derivatives of composite functional foods

Plants are the richest source of health-beneficial components. Examples of functional foods are; vegetables, oats, fruits, soybean, Pigeon pea, and maize (Baumgartner *et al*., 2020). Composite functional foods possess multiple functions necessary for survival and confer physiological effects, nutritional benefits, and substantial health benefits (Alwi *et al.,* 2021). The most valuable blends used for the composite food products formulations are obtained from their functional properties (Awuchi *et al*., 2019).

4.1 It is an essential means of preventing and managing chronic diseases, thereby prolonging life expectancy.

Various epidemiological examinations have linked the intake of certain select nutrients from functional foods to a lower likelihood of developing high blood pressure, osteoporosis, cancer, cardiovascular diseases, atherosclerosis, stroke, myocardial infarction, diabetes, depression, neurological conditions, and other diseases, thereby prolonging life expectancy (Sedigheh *et al*., 2017; Ouis and Hariri, 2018; Galanakis, 2021).

4.2 Antioxidant capacity

Functional foods contain various bioactive phytochemical macronutrient components. The different secondary metabolites with antioxidant potentials (like polyphenols, lycopene, carotenoids, flavonoids, and anthocyanin) enable it to scavenge for and fix free radicals in the body. These free radicals generated by the body cells during cellular metabolism reduce or inhibit metabolic oxidative stress causing cellular damage (Alwi *et al.,* 2021)

4.3 Lowering blood cholesterol

A wealth of evidence shows that functional foods with low-density lipoprotein cholesterol (LDL-C) affect blood cholesterol concentrations, thereby improving cardiovascular health (Baumgartner *et al*., 2020; Froyen, 2021; Sharanappa *et al*., 2021). Also, Linoleic acid, a vital fatty acid found in maize oil, provides diets with the requisite functionality required to regulate blood cholesterol (Froyen and Burns-Whitmore, 2020). The intake of resistant starch from maize (high amylose maize) has yielded significant health benefits like improving healthful microbial population, faecal excretion, fermentation, and Short-Chain fatty acid (SCFA) production in the large intestine, thereby enhancing colon health, lowering and influencing cholesterol metabolism and reducing cecal cancer risk, atherosclerosis and obesity-related complications (Cione *et al*., 2021).

4.4 Promotes healthy body weight

Composite foods that include water-soluble and insoluble fibres have a significant impact in curtailing diseases that have low-intensity chronic inflammation like obesity emanating from positive energy balance, and it appears to have a link with excess body fat and

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morbidity (Mauro and Ilaria, 2016). The deposition of fats on the visceral tissues of the human body along with free fatty acids has raised portal circulation levels leading to insulin resistance, a precarious beginning for diabetes mellitus and other cardiovascular conditions; lowering fat deposition reduces severe illness associated with this metabolic situation (Love-Osborne *et al.,* 2008). Dietary fibres with resistant starch have aided weight loss by reducing food consumption, decreasing diet caloric density, and modifying gene expressions (Keenan *et al.,* 2006).

4.5 Enhancement of gut health

Functional foods support gut health, enhancing the body's immune system (Ashaolu, 2020). Some dietary fibres are known to stimulate human health mainly through the gut's microbiome (Makki *et al*., 2018). Gut microorganisms ferment non-digestible carbohydrate prebiotics into useful metabolic products like butyrate (a critical factor in sustaining gut barrier cohesion, metabolism, and immune homeostasis of their host health. Some resistant starches have been broken-down and fermented sequentially by specialized gut microbes yielding variable effects on the gut microbiome (Dobranowski and Stintzi, 2021).

4.6 Probiotics and prebiotics provision

Functional foods provide the body with live but helpful microbial cultures (probiotics) and the nutrients they feed on (prebiotics), which helps to improve the general well-being of the body (Gibson *et al*., 2017; Tabashsum *et al*., 2020).

5. Tackling post-harvest losses and food security challenges

Global food security cannot be accomplished if challenges connected with it are not halted, one of which is post-harvest losses (PHL). This is an appraisable and computable evaluation of the reduced economic value (in both quality and quantity) occurring in a given agricultural crop product (Kitinoja and Kader, 2015). Loss in quantity is easily measurable and quick to identify because it bothers on the physical depletion of crop marketability. Still, qualitative losses are not quickly reported nor measured since it affects nutrient quality, grade, and crop safety. This should be of concern since long-term consumption of such crops can negatively impact human health (Ambuko, 2017).

Post-harvest losses are fast assuming the status of becoming a global existential threat, negatively impacting human nutrition, economic stability, and food security (Neme *et al*., 2021). According to the FAO, 30% of annual international foods cultivated for human consumption never reach intended consumers as they are either destroyed or shrivelled along the food supply chain. It is estimated that this wasted food, equivalent to 1.3 billion metric tons, could feed 1.6 billion people annually. In Africa, higher PHL of between 30-50% have been recorded; World Bank 2011 analysis evaluated the value of grains lost by African countries alone to be worth USD$4 billion (Ambuko, 2017; FAO, 2018; FAO, 2021b).

Developing countries like Nigeria are endowed with a plentiful supply of agricultural bioresources. Ugochukwu (2020), estimated the entire Nigerian agricultural value chain to be worth $85 million hectares of arable land (although it is considered highly underdeveloped). Of this amount, cultivation that produces more than 85% of their foodstuff through peasant rural household farmers only occurs on 34 million hectares. Sadly, this process can never guarantee food supplies all year round because a lot of produced food, are lost through heavy post-harvest losses (PHL) and spoilage, which often creates food insecurity.

PHL could be due to harvest mishandling, lack of proper storage facilities, inadequate rural road/ transport accessibility, and poor post-harvest processing and packaging know-how (Bolarin and Bosa, 2015; Bekele, 2021). Another worrisome development is that many of these losses also occur from microbial deterioration, pests, and rodents. Recently, farmer/herder clashes, the effect of climate change, and COVID-19 added to this menace. Nigerian Stored Products Research Institute (NSPRI), records Nigeria's annual post-harvest losses to be 50% (translating to over USD 12 billion or ₦ 3.5 trillion); this is more than 51.3 metric tonnes (Odutola, 2020; Okojie, 2021; Ukpe, 2022). For the PHL of each commodity sub-sector, grains with 15% loss recorded the most negligible losses, while fruits and vegetable commodities (50%) recorded the highest number of losses (Figure 3). These horticultural perishables have been known to have a very short shelf-life.

Globally, the commodities with the lowest minimum post-harvest losses are oil crops, pulses and cereals with a global average of 4% (Mayienga and Cachia, 2021). Other commodities all presented much higher minimum post-harvest losses for example, fruits (17%), roots and tubers (18%), sugar crops (19%) and vegetables (21%) (FAO, 2019). The comparative analysis of the Nigerian and global average commodities PHL is shown in Figure 4.

Among the grains commodity globally, wheat (about 2%) has recorded the lowest minimum PHL; next are rice (2–5%) and maize (6%). This is so since wheat is

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gleaned at 14–20% lower moisture contents than rice 20–25% and maize (18–24%). Because reduced moisture content at harvest typically results in lower losses, the corporeal attributes of these grains make these results dependable (Mayienga and Cachia, 2021).

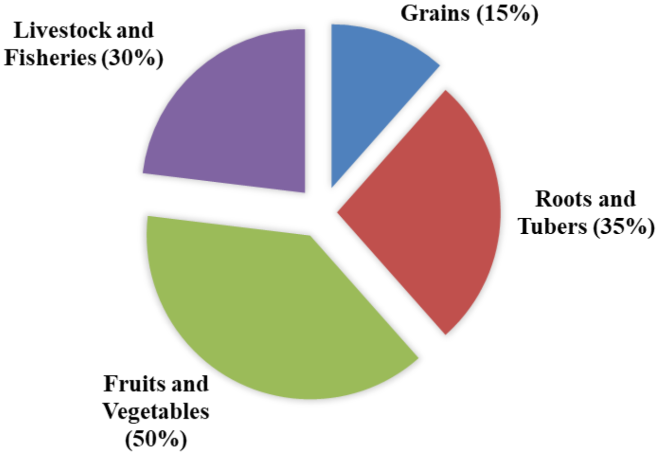

Figure 3. Nigeria's yearly percentage post-harvest losses per commodities. Source: FAO (2019) and NSPRI (2020).

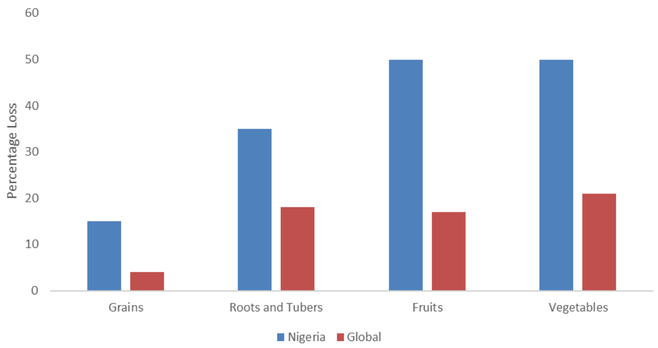

Figure 4. Comparative analysis of Nigerian and global average commodities PHL. Source: FAO (2019) and NSPRI (2020).

Credible data has been collated to support significant comparisons of minimum PHL across national territories: low-level income countries in West Africa, East Africa, and Central America registered the highest minimum PHL. In contrast, high-level income nations in South-eastern Asia and South America established lower minimum PHL. The difference in outcomes across national territories indicates superior and more efficient technology in terms of production methods (Mayienga and Cachia, 2021).

These estimates aggregate losses occurring at all levels, from farm-level production practices (where poor harvest operations and handling by farmers are responsible for farm-level Losses) to the downstream of the food supply network (which are the retail stages of consumption). The challenges at every level are distinctively relative to the context, produce and value chains (Bolarin and Bosa, 2015; Ambuko, 2017). Produce losses often translates mostly to losses in production resources such as inputs, water, and energy. Various stakeholders across the food supply chain suffer income losses, too, with findings revealing a reduction in income by 15% to 470 million small-scale farmers, while wasted farmlands and water used on food not consumed was 20% and 25%, respectively.

With the forecast that the world's human population will get to 9 billion by 2050 and the African continent coming up with most of this increment, there will have to be a 70% increase in food production to cope with surging demands. Sadly, production assets like water, energy, and land are static and in short supply. Recent analysis has shown that the increase in the inability to afford healthy diets relates to higher levels of moderate or severe food insecurity (FAO, 2021a). Agricultural development and food security are vital for national prosperity and sustainable development (FAO, 2018; GAIN report, 2019; Bekele, 2021).

As shocking as these statistics may appear, they are crucial in spotlighting the ramifications and gravity of post-harvest losses. Our focus should be on harnessing existing foods, developing their nutritive capabilities using biotechnology, and increasing the availability of these food products to various human end users for consumption. The foresightedness in tackling this menace should involve all stakeholders, such as government, non-governmental organizations, and international development partner organizations (Kitinoja and Kader, 2015).

Food security as a conceptualized idea has advanced from its conventional hub of concentrating on national food supplies in the 1990s to a more robust and broad-based definition (Omonona and Agoi, 2007). Hence, food security is now acceptably defined broadly as the ability of all family members to have sufficient access to available food supplies, meet their daily dietary requirements all year round, and live a physically functional and economically productive life without unnecessary threats. Therefore, the critical definitive criteria of food security should be:

Food security = Food availability + Food access and acquisition + Food use.

However, the humbling reality is that currently, the world has not progressed generally either towards the Sustainable Development Goal (SDG) Targets 2.1 and 2.2, which deal with ensuring all-year-round access to safe, nutritious, and sufficient food for all people and eradicating all forms of malnutrition respectively (FAO, 2021a).

6. Future outlook

The destabilization of national economies stemming

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from global-warming, COVID-19 pandemic and the more recent Russian-Ukraine imbroglio is threatening wheat exports, creating global spikes in food, fuel and agro-chemicals prices. With famine and starvation looming, the task of guaranteeing food security by harnessing indigenous agro-processed flour blends is imperative. Although it could be quite demanding particularly for developing African countries with respect to technological know-how, continuous availability of these foods to human end users at affordable rates and reducing post-harvest losses should be the goal. However, nothing good comes easy except tackled, with a positive mind-set and all stakeholders dynamic involvement, this challenging situation is surmountable.

Food research experts can adopt novel technologies that can bridge the food requirement cracks by boosting productivity and ensuring year-round supply, one of such is the use of Nanotechnology (Galanakis, 2020; Farcas *et al.*, 2021; Neme *et al.*, 2021). The implementation of these technological innovations as a policy by both governments and relevant stakeholders would go a long way in tackling post-harvest losses leading to the attainment of food sustainability.

Re-engineering and enhancing contemporary food processing systems industrially to contain excellent sensory ingredients with bioactive properties that can provide immunity for humans in the fight against known and re-emerging infections.

The composite functional food supply chain must be sustained to serve as a buffer that will help in reducing and possibly avoiding future food and health emergencies.

An overall improvement in quality assurance standards towards rising shelf life, promoting better protection and superior antimicrobial fortification over other substitutes will yield a more attractive product market value.

Nevertheless, additional exploration is essential to unravel the general wellbeing and health-related risks connected to the continuous consumption of various composite functional foods over time especially among intolerant groups.

Developing the technological capacity of indigenous agro-processed flour blends will greatly advance the bioavailability of nutrients in these food mixes by means of a variety of food processing procedures while guaranteeing the increased accessibility of these foods to human end users at affordable rates and adequately tackling the ecologically and economically untenable post-harvest losses by focusing endeavours on the reutilization of the derivatives from these previously unwanted food scraps, in so doing making our surroundings more eco-friendly (Torres-León *et al.*, 2018; Friman and Hyytiä, 2022).

7. Conclusion

The continuous high levels of poverty resulting from income inequality and the devastating global effect of COVID-19 have made consumption of immune-boosting, rich-healthy diets expensive. This situation can be alleviated by using composite functional foods obtained by harnessing comparatively advantaged indigenous flour blends from raw botanicals in each world region without recourse to importation. The practicability of developing accessible low-end but rich healthy diets by various non-wheat growing countries as an alternative for wheat flour in the preparation of ready-to-eat bakery and pastry staple meals cannot be over-emphasized. The bioactive dietary components in these food products are balanced and better than when single crop flour is milled and used. The future focus should adopt an all-round strategy in composite functional food development that considers and analyses products from conceptualization, acceptable regulation, and even chemical elucidation. These developments will accelerate the exploitation of native food crops toward producing varieties of food products. The GDP of African economies will be exponentially boosted if properly annexed while minimizing post-harvest losses. An increase in the inability to afford healthy diets promotes higher moderate or severe food insecurity levels. Agricultural development and food security are vital for attaining national prosperity and sustainable development goals.

Conflicts of interest

The authors declare no conflicts of interest on this article.

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