Chapter 5

Fermented Pulse-Based Food Products in Developing Nations as Functional Foods and Ingredients

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http://dx.doi.org/10.5772/intechopen.69170

Abstract

Pulses play a significant and diverse role in the agricultural systems and diets of underprivileged populations worldwide. They are ideal produce for reducing poverty, improving human health and nutrition, and enhancing resilience of the ecosystem. Fermentation is a processing technique that has been used for decades to transform food produce with improved health, functional, and nutraceutical benefits. In tandem with the United Nations' (UN's) sustainable development goal Number 3, fermented food products from pulses with health benefits align with this initiative to end hunger, achieve food security, and improve nutrition. In solidarity with the celebration of International Year of Pulses 2016 (IYP2016) and considering the relative neglect of pulses as compared with other food groups, this chapter would be vital in positioning pulses and fermented products from them as readily available functional foods. With increased interest in fermentation, fermented pulse-based foods have been identified as excellent sources of bioactive and functional foods. Thus, fermented pulse-based products present a viable alternative, relatively available, affordable, and cheap source of foods with properties beyond that of basic nutrition.

Keywords: pulses, fermented foods, functional foods, bioactive compounds

1. Introduction

Following the resolution of the UN on 20 December, 2013, the 68th general assembly declared the year 2016 as the International Year of Pulses (IYP2016) [1], which was celebrated and sponsored by the Department of Science and Technology (DST), South Africa, during the

2016 Autumn International Food Safety and Security Conference hosted by the University of Johannesburg, South Africa. This was designated as such to promote public awareness on the usage of pulses and their potential as critical sources of plant-based proteins. The IYP2016 is rather timely and appropriate considering the relative neglect of pulses when compared to other crops despite its significant role pulses toward ensuring food security and nutrition.

While other processing techniques have been used for the transformation of pulses for food, fermentation is significant because it is known to improve sensory qualities and shelf life, reduce pathogenic microorganisms, and exert functional and health beneficial effects to food [2–5]. Due to its benefits and subsequent findings, developments of novel pulse-based foods through fermentation have been promoted [6]. Fermented pulse-based food contains a number of functional compounds including phytochemicals (phenolic compounds), lectins, polysaccharides, and phytates that confer and play significant role in health [7, 8]. In this regard, this chapter is thus focused on fermented pulse-based foods and the substantiated health-promoting components in them. This is vital considering the fact that these fermented foods form basic sources of diet and primary sources of bioactive compounds in many developing and underdeveloped nations. Furthermore, considerable emerging evidence showing the potential benefits of these fermented pulse-based foods is described.

2. Description of pulses and an overview of their composition

The name "pulses" is generally reserved for crops harvested solely for the dry seed (**Table 1**) and used interchangeably with grain legumes. While all pulses are considered legumes, not all legumes are pulses [9]. The Codex Alimentarius Commission as well as the Food and Agricultural Organization (FAO) of the United Nations defines pulses as dry seeds of leguminous plants, which are usually distinguished from leguminous oilseeds with their low fat content [1–3]. Although different pulse varieties are grown in 173 countries around the world, 11 of them are primarily recognized by FAO [9]. These are presented in **Table 1** along with their documented world production as at 2015.

Pulses are important crops that have a balanced nutritional composition and are among the most important sources of cheap and readily available starch, carbohydrate, protein, dietary fiber, minerals, and vitamins in food [9, 11–15]. Pulses also contain a number of bioactive compounds including phytates, oligosaccharides, enzyme inhibitors, and phenolic compounds that have been reported to positively impact health [7, 8, 16]. For human consumption, pulses are not eaten in its raw state, but typically after subsequent food processing, including boiling, cooking, puffing, grinding, germination (sprouting), and fermentation to increase their sensorial quality, appeal, esthetic value, and use.

Plant proteins are now being regarded as excellent, versatile, and available sources of functional and biologically active food components [9]. The evolution and drive toward the consumption of plant proteins have been influenced by the continued need and drive of health professionals agitating for partial replacement of animal proteins with plants that possess better and cheaper nutritional components. Aside from other components, pulses have been

Common name	Native name	Botanical name	World production[δ]
Dry beans	Kidney bean, navy bean, pinto bean Lima bean Scarlet runner bean Tepary bean Adzuki (azuki) bean Mung bean, golden gram, green gram Black gram, urad Ricebean Moth bean	*Phaseolus vulgaris* *Phaseolus lunatus* *Phaseolus coccineus* *Phaseolus acutifolius* *Vigna angularis* *Vigna radiate* *Vigna mungo* *Vigna umbellate* *Vigna aconitifolia*	27591.35
Dry broad beans	Horse bean Broad bean Field bean	*Vicia faba equina* *Vicia faba* *Vicia faba*	5568.67
Dry peas	Garden pea Protein pea	*Pisum sativum* var. *sativum* *Pisum sativum* var. *arvense*	12536.12
Chickpea	Bengal gram, garbanzo	*Cicer arietinum*	13741
Dry cowpea	Black-eyed pea, black eye bean	*Vigna unguiculata*	5602.72
Pigeon pea	Arhar/toor, cajan pea, Congo bean, gandules	*Cajanus cajan*	4890.10
Lentil		*Lens culinaris*	4952.12
Bambara groundnut	Earth pea	*Vigna subterranea*	160.38
Vetch	Common vetch	*Vicia sativa*	905
Lupins		*Lupinus* sp.	1014.02
Minor pulses	Lablab, hyacinth bean Jack bean Sword bean Winged bean Velvet bean, cowitch Yam bean	*Lablab purpureus* *Canavalia ensiformis* *Canavalia gladiate* *Psophocarpus tetragonolobus* *Mucuna pruriens* var. *utilis* *Pachyrhizus erosus*	NA*

δProduction in KT obtained from Ref. [10].
*NA, not available.

Table 1. Commonly consumed pulses and world production (KT).

identified as excellent sources of plant proteins, which are accumulated during their development [9, 17]. Pulses have been incorporated in various forms of traditional and staple diets to supplement basic protein and energy requirements and provide functional properties beneficial to human health [9, 16, 18, 19].

The most important pulses intended for human consumption include adzuki bean, black gram, chickpea, dry broad bean, dry cowpea, field pea, mung bean, green gram kidney bean, lentil, lupin, pigeon pea, lima bean, moth bean, and rice bean [20] with their comparative % protein provided in **Table 2**. Pulses provide between 20 and 30 g of protein per 100 g, twice as

Scientific names	Common names	Protein (per 100g)
Cajanus cajan	Pigeon pea	21.70
Cicer arietinum	Chickpea	21.70
Lens culinaris	Lentils	24.63
Phaseolus lunatus	Lima beans	21.46
Phaseolus vulgaris	Black beans Kidney beans Pinto beans	23.58 24.37 21.42
Vigna angularis	Adzuki beans	19.87
Vicia faba	Faba beans	26.12
Vigna mungo	Black gram	25.21
Vigna radiata	Mung beans	23.86
Vigna mungo	Vigna mungo	25.21

Table 2. Comparison of protein content of major pulse crops [21].

much as is found in grains and similar to that in meat [20]. Additionally, pulses do not contain residues of hormones and antibiotics like it is the case with animal protein sources such as beef and milk [1]. Nevertheless, while antibiotic and hormones might be absent, they could possibly be contaminated with pesticide and herbicides, used during cultivation. Pulses also possess a considerable amount of vitamins A and B along with iron, phosphorus, and calcium and thus serve as a food of high calorie and nutritive value [1, 7, 9].

3. Fermentation and fermented pulse foods in developing nations

Pulses have been processed in developing nations for centuries using traditional processing techniques of grinding, fermentation, steeping, germination, dehulling, etc. and prior to consumption for further use. Other novel food processing including micronization, microwave processing, high pressure processing (HPP), pulse electric field (PEF), irradiation, and extrusion techniques have found potential use and application for pulse processing. Nevertheless, fermentation remains largely important for pulse processing and gaining increased attention because of its improved functionalities, increase nutritional composition, and production of bioactive compounds [16, 22].

Fermentation can be generally defined as a processing technique used to convert substrates into new products through the action of microorganisms [5]. Fermentation is also used in a broader sense for the intentional use of microorganisms to obtain useful products for humans on an industrial scale. Such industrial products may include biomass, enzymes, primary and secondary metabolites, recombinant, and biotransformation products. The biochemical changes that occur throughout the food fermentation process lead to the modification of the substrate (starch or sugar) and production of other compounds (such as acids and alcohols) [5]. Fermentation improves the texture, appearance, color, flavor, shelf life, and also protein digestibility of pulses [5, 16]. It further decreases the presence of "antinutritional factors" including phytate, lectins, oligosaccharides, and protease inhibitors [5, 16, 23]. Especially in rural and traditional communities, spontaneous fermentation is mostly used for pulse processing. However, better and improved fermentation techniques in terms of specific strain development have been encouraged and introduced to improve product and nutritional quality, microbial safety, and product yield. In addition to fermentation, other processing operations could involve baking, cooking, and compositing, among others.

3.1. Microbiology and biochemistry of pulse fermentation

The microbiota of fermented pulse-based foods is largely dependent on temperature, pH, water activity, type of substrate, and salt levels. The three major types of microorganisms used during fermentation of pulses are bacteria of the genus *Bacillus*, lactic acid bacteria (LABs); some fungal species (**Table 3**); and possibly yeasts. In majority of these pulse-based fermented foods, the fermentation process is spontaneous (natural), and thus a mixture of microorganisms may act parallel or sequentially. This may thus cause changing and non-consistent products and possible production of pathogenic microorganisms and toxins [4, 5]. Nevertheless, LABs are dominant (**Table 3**), normally fastidious and grow willingly in most food substrates reducing the pH rapidly to a point where other competing organisms are no longer able to grow [24]. Several industrial fermentations have also applied LABs for the production of functional foods and the production of enzymes/metabolites. For ages, indigenous or traditional fermented foods have formed an essential part of the diet and can be prepared in the cottage industry using simple techniques and household equipment [25–27]. Fermented pulse-based foods are more abundant and available in developing nations, especially in India where it is passed on as trade secrets in the communities of certain families, a practice protected by custom [25]. The several available fermented pulse-based foods are summarized in **Table 3**.

Fermentation of pulses as with other food crops is associated with reduction of pH; changes in carbohydrates (starch, fibers, saccharides, sugars), proteins (amino acids), and lipids; "antinutritional" factors; and enzymatic degradation of different compounds [4, 5]. It also leads to the improvement of texture, taste, and aroma of the final product. As further described in the later section of this chapter, effect of fermentation on the composition of pulses varies; substantial evidence suggests improvement in nutritional and beneficial composition. Aside from various modifications, fermentation of pulses is also associated with the formation of compounds as a result of microbial actions on endogenous compounds. Such compounds include alcohols, ketones, organic acids, and aldehydes that further contribute to the distinct aroma associated with fermented pulse-based foods.

3.2. Evolvement and market for fermented pulse-based foods

As earlier presented in **Table 3**, fermented pulse-based food products are ubiquitous in developing nations, with some being used as snacks, meal, or spices. From traditional methods of fermentation and preparation of these foods (which are still largely common), there has been

Product	Produce	Country of origin	Microbial group responsible for fermentation	Mode of consumption/form	References
Amriti	Black gram	India	NR	Snack	[28]
Bedvin roti	Black gram, opium seeds, or walnut	India	NR	Breakfast or snack food	[29]
Bhallae	Black gram	India	*Bacillus subtilis, Candida curvata, C. famata, C. membranifaciens, C. variovaarai, Cryptococcus humicola, Debaryomyces hansenii, Enterococcus faecalis, Geotrichum candidum, Hansenula anomala, H. polymorpha, Kluyveromyces marxianus, Lactobacillus fermentum, Leuconostoc mesenteroides, Pediococcus membranaefaciens, Rhizopus marina, Saccharomyces cerevisiae, Trichosporon beigelii, T. pullulans, Wingea robertsii*	Side dish	[30]
Condiment	Pigeon pea	Nigeria	NR	Condiment	[31]
Dalbari (Urad dalbari)	Lentil	India	NR	Snack	[32]
Dawadawa	Local pulses	West and Central Africa	*B. licheniformis, B. subtilis*	Condiment, meat substitute	[16]
Dhokla	Bengal gram	India	*B. cereus, Ent. faecalis, Leuc. mesenteroides, L. fermenti, Tor. candida, Tor. pullulans*	Snack	[33–35]
Dosa	Black gram	India	*Bacillus* sp., *L. fermentum, Leuc. mesenteroides, Streptococcus faecalis*, yeast	Breakfast or snack food	[16]
Idli	Black gram	India, Sri Lanka	*L. delbrueckii, L. fermentum, Lactococcus lactis, Leuc. mesenteroides, Strep. lactic, Ped. cerevisiae*, yeast	Breakfast food	[16]
Khaman	Bengal gram dhal or Chickpeas	India	*Bacillus* sp., *L. fermentum, Leuc. mesenteroides, Lact. lactis, Ped. acidilactici*	Snack	[33, 36, 37]
Maseura	Black gram	Nepal, India	*B. laterosporus, B. mycoides, B. pumilus, B. subtilis, C. castellii, Ent. durans, Ped. acidilactici, Ped. pentosaceus, L. fermentum, L. salivarius, S. cerevisiae, Pichia burtonii*	Dry, ball like, brittle, condiment	[38]
Mashbari	Black gram, spices	India	*Bacillus* sp. A_{94}, *Lactobacillus sp., S. cerevisiae*	Staple food	[39]

Product	Produce	Country of origin	Microbial group responsible for fermentation	Mode of consumption/form	References
Masyaura	Black gram or green gram	Nepal, India	*Aspergillus niger*, *C. versatilis*, *Cladosporium* sp., *Lactobacillus* sp., *Ped. acidilactici*, *Ped. pentosaceus*, *S. cerevisiae*, *Penicillium* sp.	Side dish	[40, 41]
Papad	Bengal gram, black gram, lentil, red or green gram	India	*C. krusei*, *S. cerevisiae*.	Condiment or savory food	[27, 37]
Probiotic food	Mung bean	China	*L. plantarum* B1-6	Beverage	[6]
Sepubari	Black gram, dangal, spices	India	*Bacillus* sp. A_{31}., *Lactobacillus* sp., *S. cerevisiae*	Special dish in marriage feast	[39]
Teliye mah	Black gram	India	NR	Semi solid	[29]
Tempeh	Chickpeas, local pulses	Indonesia, New Guinea, Surinam	*Asp. oryzae*, *Rhiz. oligosporus*	Breakfast food or snack	[16]
Tempe Benguk	Velvet bean seeds	Indonesia	*Rhiz. arrhizus*, *Rhiz. oligosporus*	Alkaline, solid, fried cake/ breakfast food	[42]
Tempe Kecipir	Winged bean seed	Indonesia	*Rhiz. achlamydosporus*, *Rhiz. arrhizus*, *Rhiz. oligosporus*, *Rhiz. oryzae*	Alkaline, solid, fried cake/ breakfast food	[43]
Tempe Koro Pedang	Jack bean seed	Indonesia	*Rhiz. achlamydosporus*, *Rhiz. arrhizus*, *Rhiz. oryzae*	Alkaline, solid, fried cake/ breakfast food	[43]
Vadai	Black gram	India	*Leuconostoc* sp., *Pediococcus* sp., *Streptococcus* sp.	Paste, side dish	[34]
Wadi	Black gram and oil	India	*L. fermentum*, *L. mesenteroides*	Spicy condiment or an adjunct for cooking vegetables or rice	[27, 44]
Wari	Bengal gram or Black gram	India, Pakistan	*B. subtilis*, *Candida.* sp., *Cryptococcus humicolus*, *Debaryomyces* sp., *Ent. faecalis*, *G. candidum*, *H. anomala*, *Kl. marxianus*, *L. bulgaricus*, *S. cerevisiae*, *Strep. thermophiles*, *Trich beigelii*, *Win. robetsii*	Snack, fried balls, brittle, side dish	[16, 45, 46]

NR, not reported.

Table 3. Pulse-based fermented foods in developing countries.

some improvement toward the commercialization of few of these fermented pulse-based food products. Through industrialization and the advent of new technologies, significant developed and commercially available fermented pulse-based foods are *tempeh*, which has evolved to being available as salads and burgers; *dawadawa* (dried and ground form); and *dhokla* flour. Challenges, however, hampering the development and subsequent commercialization have been affordability of starter cultures and inadequate access to appropriate technology. The use of starter cultures in fermentation processes would largely assist in standardizing the fermentation process to ensure consistency, hygiene, and improved sensory quality. The challenge of accessing commercially available starter cultures for use in traditional, rural, and urban homes and small-scale industry is quite significant in developing nations. Related to this is also limited access to necessary technology, equipment, and expertise for production of fermented pulse-based foods, which is needed for development and provision of shelf-stable products.

Considering the ever-growing increasing market for functional foods in the world, with an increase of 25% from 2013, the global functional food market is expected to reach US$54 billion in 2017 [47]. This demand is expected to be largely driven by the need for products with substantiated health benefits, which can address chronic diseases including obesity, diabetes, cardiovascular diseases, and cancer. With such increase in demand coupled with the advent of new and novel processing technologies and the wealth of ongoing research, there is huge potential for the development of new functional products from fermented pulses which could be subsequently commercialized. Although few of these are already available in the market, there is still need for concerted efforts to scale up their production and make them more readily available.

4. Major functional components in fermented pulse-based foods and effects of fermentation on them

As indicated in the earlier sections of this chapter, aside basic nutrition, fermented pulses are sources of important functional components that have been proven critical for human health. These benefits can be attributed to various bioactive and health-promoting components embedded in them [20, 48]. It should also be noted that while fermentation has been used for ages to transform and modify pulses to products with improved benefits, studies have only recently sought a better understanding of the modification and its effects during pulse processing. As one would envisage, fermentation can have an effect on the bioactive components present and subsequent health-promoting benefits derived from fermented pulse-based foods. Examples of such major bioactive components and documented changes are subsequently discussed in the proceeding sections of this chapter.

4.1. Phenolic compounds

Over the years, there has been an increasing interest and desire in phenolic compounds due to their beneficial activity in relation to health. According to Dueñas et al. [49], pulses are excellent sources of phenolic compounds, which are largely accumulated in their hulls. The most essential phase of phenolic metabolism is the accumulation of phenols in plant tissues, as this is responsible for biological activity [50]. Several factors affect the concentration of phenols in pulses, including the degree of maturity at time of harvest, climatic and edaphic conditions, processing (e.g., fermentation), and storage conditions [50, 51].

Phenolic compounds consist of the −OH bonded directly to an aromatic hydrocarbon group and the major ones in pulses include flavonoids, tannins, saponins, and phenolic acids [16, 20]. These compounds impact pigmentation, flavor and taste in foods, and antioxidant activities and interact with proteins as a result of their radical-scavenging capacity [52]. Studies have shown that antioxidants contained in fermented pulses may mitigate the prevalence of some forms of cancer [53–58]. Ademiluyi et al. [57] reported the hypoglycemic and antiacetylcholinesterase activities of fermented bambara in rats and attributed this to the presence of phenolic compounds and other phytochemicals. Phenols in pulses and their fermented products have also been reported to exhibit strong antimutagenic, anti-inflammatory, and anticarcinogenic properties and have the capacity to modulate some important cellular enzyme functions [55, 59, 60]. Reduced levels of oxidative damage to lymphocytic DNA have also been linked to consumption of fermented pulse-based foods rich in antioxidants [50]. Phenolic compounds in fermented pulses have been documented to exhibit antioxidant properties. As reported by Moktan et al. [61], *idli* and *dhokla* exhibited metal chelating, lipid peroxidation, and high free radical-scavenging activities. Likewise, common bean and *tempeh* products exhibited radical-scavenging and antioxidant activities. In an in vivo study using hypercholesterolemic mice, the antioxidants in fermented mung bean were found to reduce the level of serum lipid and liver enzyme profiles [62]. Epidemiological studies have repeatedly shown a positive indication regarding the increased consumption of polyphenolic-rich diets and associated reduction of chronic human diseases [63, 64]. Clinical studies on pulses have also attested that phenolic compounds confer some health benefits in humans, including the reduction of cardiovascular diseases, weight management, cancer prevention, and diabetes control [65–68].

Available literature on the fermentation of pulses has documented both an increase and decrease in the phenolic compounds. An increase in hydroxybenzoic acid and (+)-catechin content was reported in spontaneously fermented lentils [69], while similar increase in free soluble phenols observed during the fermentation of some underutilized pulses [55]. Conversely, a reduction of conjugated forms of ferulic acid, *p*-cumaric, hydroxycinnamic derivatives, and bound phenols was observed during the fermentation of pulses [49, 55]. Surprisingly, same authors reported the synthesis of tyrosol and an increase in free quercetin due to the hydrolysis of quercetin glucosides [49]. Nevertheless, such documented changes have been attributed to the action of glycosidases and esterases from LABs releasing free aglycones, phenolic acids, hydroxyl-cinnamic acids, and less esterified proanthocyanidins and the transformation of bound to free phenolics during fermentation [49, 55, 70–73].

4.2. Protease inhibitors, lectins, and phytates

Proteases, lectins, and phytates are group of compounds normally regarded to as minor components of pulses. As documented by Vasconcelos and Oliveria [74] and Boye et al. [75], they were regarded as antinutrients in the past, because they negatively affect nutrient digestibility and alter glucose transportation. Referring to these minor components as "antinutrient" could however be a misnomer, considering their involvement in health-promoting processes [7, 16].

Protease inhibitors found in pulses act on either or both of the serine proteases chymotrypsin and trypsin and are important from the nutritional point of view [7, 76]. They are found in relatively high quantities in pulses compared to other plant foods and can be broadly classified as either Bowman-Birk or Kunitz type, based on their molecular masses and cystine contents [75]. Inhibitors of the Kunitz type have two disulfide bridges with a molecular mass of approximately 20 kDa and act specifically against trypsin, while the Bowman-Birk type contains seven disulfide bridges, with a molecular mass between 8 and 10 kDa, and inhibits chymotrypsin and trypsin simultaneously at independent binding sites [7, 76]. Although protease inhibitors can block chymotrypsin and trypsin activities, thus reducing protein digestibility, the Boman-Brik family of protease inhibitors has been reported to show anti-inflammatory and anticarcinogenic effects in human colon cancer cells [77–81].

Pulses are the main sources of lectins in everyday human diet, although fermentation is reported to reduce the lectin content of pulses [7, 82]. Lectins are glycoproteins, which have the ability to agglutinate red blood cell in vitro and are thus referred to as phytohaemagglutinins [83]. Like other presumed pulse antinutrients, lectins are now being considered as important in immunological and cell biology, with potentials for clinical applications [7]. They can inhibit tumor growth and exert antimicrobial, immunomodulatory, and HIV-1 reverse transcriptase inhibitory activities [84]. In other studies, lectins are being adopted for the discovery of cancer markers that are proteinaceous in nature via a natural glycoprotein microarray approach [7].

Phytic acid also known as inositol polyphosphate, inositol hexakisphosphate (IP6), or phytate (when in salt form) is found within the hulls of pulses. It is known to be the main storage form of phosphorus in plants [85]. Phytate and some of its secondary products are regarded as antinutrients because of their active role in chelating important minerals such as magnesium, calcium, zinc, and iron, thus contributing to mineral deficiencies [85, 86]. However, the health benefits of phytate have been "rediscovered," thus propelling a gradual change and perspective in its classification as an antinutrient. For example, phytic acid could play a role in regulating DNA repair via nonhomologous end joining [87] and other cellular functions such as nuclear messenger RNA export [7]. In vitro and in vivo studies of fermented pulses have also shown that inositol hexaphosphate (InsP6, phytic acid) exhibits potent anticancer properties (both therapeutic and preventive), tumor abrogation, host defense mechanism, and reduction of cell proliferation [88]. Phytic acids also diminish the bioavailability of toxic heavy metals and demonstrate antioxidant activity [89]. Phytic acid is used as a food additive (preservative) E391 [90], though its exact intracellular physiological roles are still unclear [91].

Fermentation was reported to have reduced trypsin inhibitor activity of mucuna and faba bean [23, 92] and was hypothesized as a consequence of bacterial proteases during the fermentation [92]. In studies conducted by Akpapunam and Achinewhu [93] and Khattab and Arntfield [94], fermentation was observed to reduce the phytic acid and trypsin inhibitor activity in fermented pulses. Such reduction of phytate and phytic acid has been ascribed to the endogenous phytase seeds and that of other microorganisms, which causes hydrolysis of the phytic acid into orthophosphate and inositol and microbial degradation of the phytates [93, 95, 96]. Likewise, a reduction in the lectin content of lentils fermented for 72 h was reported by Cuadrado et al. [82]. This was ascribed by the authors to proteolytic degradation of lectin protein and changes in lectin-protein structure [82].

4.3. Fiber and saccharides

A thorough review of dietary fiber in pulses has been presented in the literature [97] and, accordingly, identified as good sources of both soluble and insoluble dietary fibers. When unprocessed, pulses could contain approximately 15–32% total dietary fiber, of which about one-third to three-quarters is made up of insoluble fiber, while the rest is soluble fiber [66]. Soluble fibers found in pulses comprise of oligosaccharides such as pectin, stachyose, verbascose, and raffinose, whereas, the insoluble ones include lignin, hemicellulose, and cellulose [16, 98, 99]. Major health benefits linked to dietary fiber include laxation and reduced risk of being overweight, cardiovascular diseases, and diabetes [100]. Particularly in fermented pulses, the fiber contents can lower the risk of many diseases such as diabetes, coronary heart diseases, obesity, and some forms of cancer [101]. Fibers (in particular insoluble fibers) provide physicochemical functionality to foods such as fecal bulking via its ability to hold and bind liquids such as water and fat. While soluble fiber ferments in the stomach, thus enhancing colon health via lowered pH, production of short-chain fatty acids (SCFAs), and potential microbiota changes in the colon [66, 99]. Soluble fiber has also been linked with reduction in cholesterol levels, total and low-density lipoprotein, and insulin resistance [102].

Essentially, pulse starches contain higher amylose content with high capacity for retrogradation, thus reducing starch digestion rate [103]. Slowly digestible starches and resistant starches from pulses have been linked to management of diabetes and promotion of satiation [103, 104]. Fermented pulse-based foods such as *tempeh* and *idli* are products that have been recognized as good sources of resistant starches, making them suitable for dietary strategies to manage blood glucose levels [16, 105–107]. Oligosaccharides in pulses and its fermented substrates may also be considered as prebiotics, which could be beneficial to human health [66, 108]. Pulses with their abundance of non-starch polysaccharides, oligosaccharides, and resistant starch are low glycemic index (GI) foods with GI values within 28–52 [109–113]. According to Yeap et al. [114], fermented mung bean products have been recommended for the management of diabetes due to their low GI and have assisted in reducing the prevalence of diabetes in Asia. The cardioprotective effect conferred by fermented pulse-based foods could be due to the synergistic action of the pulse oligosaccharides, resistant starch, protein, minerals, vitamins, and phytochemicals [80, 115, 116]. All these beneficial properties of dietary fiber and saccharides have led to increased interests in its use in food formulations in the food industry [99].

Studies in literature have largely suggested that fermentation increases the digestibility of fiber, starches, and saccharides [117–119]. Reduction or total elimination of raffinose oligosaccharides, verbascose, and stachyose during lactic acid and fungal fermentation of pulses has been reported in in vitro and in vivo studies [16, 120]. Yeast fermentation of peas and kidney beans, however, resulted in increase of oligosaccharides [16]. Adewunmi and Odunfa [121] investigated the effect of fermentation on the oligosaccharide content of two common *Vigna unguiculata* beans (*drum* and *oloyin*) in West Africa and observed that the stachyose content of drum bean slurry decreased by over 50% when fermented for 72 h using *Ped. acidilactici, Lactobacillus plantarum*, and *L. fermentum*. Likewise, a decrease of about 67% of stachyose content of *oloyin* was observed when fermented under similar conditions. However, the sucrose content of both beans was observed to increase significantly for all tested organisms under the same fermentation conditions [121]. They attributed these observations to the α-galactosidase enzyme producing ability of the studied organisms which breaks down the α-1,6-glycosidic bonds. In an earlier study by Odunfa [122], a similar observation was made when stachyose content of locust beans fermented for 24 h decreased. The decrease was attributed to the hydrolyzation of the oligosaccharides to simple reducing sugars by α- and β-galactosidase [122]. In a similar study, Tewari and Muller [45] reported a reduction from 4.4 to 0.6% of total raffinose and stachyose concentration after fermentation of black beans and soybean with *L. bulgaricus* and *Streptococcus thermophiles* [45]. Both increase and decrease in the fiber composition of fermented pulses have been reported in the literature. A decrease in soluble and neutral dietary fiber, cellulose, and hemicellulose in some fermented pulses was reported by Veena et al. [105] and Granito and Alvarez [107], while an increase in total dietary fiber and lignin has equally been reported by Veena et al. [105], Granito and Alvarez [107], and Vidal-Valverde [117].

4.4. Proteins and peptides

Pulses constitute an excellent source of dietary protein, which is accumulated during the growth phase of the plant; hence, pulse seeds that are mature are usually high in protein content and other nutritional components [123]. On dry weight basis, lentil, chickpea, and dry pea contain approximately 28.6, 22, and 23.3% protein, respectively, which may vary slightly depending on growing conditions, maturity, and variety [123, 124]. A greater part of pulse proteins is in the form of storage proteins which fall which are categorized into glutelins, albumins, and globulins depending on their solubility properties. Glutelins are soluble in dilute acid and base and account for between 10 and 20% pulse proteins, albumins (water soluble) also account for 10–20% protein in pulses, and globulins which are soluble in salt water constitute up to 70% of the total proteins found in pulses [123–125].

Peptides on the other had are protein molecules that are smaller than 10 kDa and may occur naturally or are derivatives of cryptic sequences of inherent natural proteins [126, 127]. Essentially, they mainly are derived via hydrolysis by microbial, digestive, and plant proteolytic enzymes [128]. Hydrolysis of pulse proteins occurs during fermentation, which alters protein functionality through the modification of physical size as well as its surface chemical properties [129]. Bioactive peptides formed during this process can show multifunctional characteristics and confer positive effects on human health through various influences on the gastrointestinal, cardiovascular, nervous, and immunological [130]. Peptides and hydrolysates from mug bean, pea, and chickpea have been investigated for various therapeutic activities such as antioxidant capacity, copper-chelating activity, and enhancement of mineral absorption/bioavailability, antiproliferative and antimicrobial properties, and angiotensin-converting enzyme (ACE) activity [131].

Protein and their adhering/conjugated peptides are significant minor components in fermented pulse-based foods. The hydrolysis of these compounds during fermentation can affect protein functionality through a modification of the protein chemical properties and physical size, increase in the number of ionisable amino and carboxylic groups leading to increased protein solubility, water holding capacity, and the formation smaller peptide fragments [66, 129, 132, 133].

In a study conducted by Xiao et al. [133] on solid-state fermentation of chickpea flour with *Cordyceps militaris*, the authors observed increased amounts of true protein, crude protein, and essential amino acids, and further analysis showed that proteins contained in fermented chickpeas were predominantly composed of lower molecular mass than that of the unfermented chickpeas. Results from the same study revealed that protein digestibility, water absorption index, fat absorption capacity, and emulsification capacity were also enhanced by fermentation. Lee et al. [134] observed the formation of bioactive peptides as a result of proteolysis during fermentation. Likewise, the production of angiotensin I-converting enzyme (ACE) was reported during fermentation of mung bean [6]. Jung et al. [135] availed that enhanced emulsification capacity observed in fermented pulses is due to the yield of low-molecular-mass peptides which have the ability to easily migrate to the water-oil interface, hence resulting in a more stable emulsion. These changes in functionalities, however, depend on the degree of hydrolysis and on the nature of the proteins [130].

Other important nutritive and nonnutritive bioactive components of fermented pulses include phytosterols, vitamins, minerals, squalene, saponins, defensins, phytoestrogens, and fatty acids. Detailed description of these other components can be found in documented studies in the literature [7, 16, 136–138]. Nonetheless, other substantiated health benefits of fermented pulses include anticancer activities, reduction of aging and stress, probiotic effects, reduces the risk of chronic diseases, and the general improvement of human well-being [16, 20, 65, 116, 139–142].

5. Development of novel functional foods from fermented pulses

As indicated early on in this chapter, fermentation of pulses to obtain different products generates vital molecules including bioactive peptides, phytochemicals, fibers, saccharides, and other compounds with substantiated health benefits. This thus opens doors for the development of novel foods from these food crops. Although conventional functional fermented foods are saturated with products from cereals and dairy, nondairy foods are gradually gaining global prominence. Coupled with the strict religious/dietary requirements of certain populations in the developing nations and the continued demand and drive for consumption of vegetable proteins, fermented pulse-based foods offer an excellent substitute in this regard. In addition, they should also be explored as technological ingredients for the development of new and novel, healthy foods. As earlier indicated, few of these fermented pulse-based foods commercially exist, but there is still a huge potential and opportunity for the development of novel functional fermented pulse-based food products with improved functionality. With the advent of different innovative technologies, fermented pulse-based foods have enormous prospects and potential for the delivery of functional foods to the populace and intending consumers. With the provision of such, it is envisaged that consumers may be willing to pay for such products with improved functionalities and quality. While these fermented pulse-based functional foods offer considerable market potential, studies and detailed in vivo experiments must be properly done prior to commercialization of such novel products.

6. Conclusion and future prospects

Owing to their relative availability, pulses are recognized as significant sources of food. Nevertheless, they are regarded as "food for the poor" in most developing nations. Fermentation as a food processing technique can improve the quality and other health-promoting benefits of pulses. As evident from earlier studies reviewed herein, consumption of such fermented pulse-based foods would thus be beneficial and largely contribute to nutrition and food security. Although these fermented pulse-based foods are readily available, the daily per capita consumption in traditional settings has been declining in recent years, and this is ironically associated with an increase of chronic diseases plaguing both developing and developed countries. While some of the inherent bioactive compounds in fermented pulse-based foods could possibly inhibit nutrient availability, fermentation can effectively reduce their ability to do this, thus ensuring that the bioactive compounds present confer some functional activities.

There is an existing potential market for functional foods, but the availability of shelf-stable products can hinder their prospects. As such, mechanisms to ensure access to technology and expertise among local and small-scale food processors should be enhanced. Although cost might hinder the provision of commercially available starter cultures, delivery of such starter cultures for improved and effective fermentation could be achieved using dried forms of previous fermented products (with viable fermenting organisms), for subsequent use. Most importantly increasing awareness of pulses and subsequent fermented products from such crops as sources of functional and health-promoting foods would be the role of government, nongovernmental organizations, and other relevant stakeholders within the health and other related sectors. This will to a large extent ensure that developing nations achieve the much-needed and envisaged food and nutrition security.

Acknowledgements

This work was supported via the Global Excellence and Stature (GES) Fellowship of the University of Johannesburg (UJ) granted to the main author (Adebo, O.A). This work was also partly supported by the National Research Foundation (NRF) Center of Excellence (CoE) in Food Security cohosted by the University of Pretoria (UP) and the University of Western Cape (UWC), South Africa.

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