We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

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

Oluwafemi Ayodeji Adebo, Patrick Berka Njobeh,
Janet Adeyinka Adebisi, Sefater Gbashi,
Judith Zanele Phoku and Eugenie Kayitesi

Additional information is available at the end of the chapter

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

^oProduction 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)
<i>Cajanus cajan</i>	Pigeon pea	21.70
<i>Cicer arietinum</i>	Chickpea	21.70
<i>Lens culinaris</i>	Lentils	24.63
<i>Phaseolus lunatus</i>	Lima beans	21.46
<i>Phaseolus vulgaris</i>	Black beans	23.58
	Kidney beans	24.37
	Pinto beans	21.42
<i>Vigna angularis</i>	Adzuki beans	19.87
<i>Vicia faba</i>	Faba beans	26.12
<i>Vigna mungo</i>	Black gram	25.21
<i>Vigna radiata</i>	Mung beans	23.86
<i>Vigna mungo</i>	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. Evolvment 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
<i>Amriti</i>	Black gram	India	NR	Snack	[28]
<i>Bedvin roti</i>	Black gram, opium seeds, or walnut	India	NR	Breakfast or snack food	[29]
<i>Bhallae</i>	Black gram	India	<i>Bacillus subtilis</i> , <i>Candida curvata</i> , <i>C. famata</i> , <i>C. membranifaciens</i> , <i>C. variovaarai</i> , <i>Cryptococcus humicola</i> , <i>Debaryomyces hansenii</i> , <i>Enterococcus faecalis</i> , <i>Geotrichum candidum</i> , <i>Hansenula anomala</i> , <i>H. polymorpha</i> , <i>Kluyveromyces marxianus</i> , <i>Lactobacillus fermentum</i> , <i>Leuconostoc mesenteroides</i> , <i>Pediococcus membranaefaciens</i> , <i>Rhizopus marina</i> , <i>Saccharomyces cerevisiae</i> , <i>Trichosporon beigelii</i> , <i>T. pullulans</i> , <i>Wingea robertsii</i>	Side dish	[30]
Condiment	Pigeon pea	Nigeria	NR	Condiment	[31]
<i>Dalbari (Urad dalbari)</i>	Lentil	India	NR	Snack	[32]
<i>Dawadawa</i>	Local pulses	West and Central Africa	<i>B. licheniformis</i> , <i>B. subtilis</i>	Condiment, meat substitute	[16]
<i>Dhokla</i>	Bengal gram	India	<i>B. cereus</i> , <i>Ent. faecalis</i> , <i>Leuc. mesenteroides</i> , <i>L. fermenti</i> , <i>Tor. candida</i> , <i>Tor. pullulans</i>	Snack	[33–35]
<i>Dosa</i>	Black gram	India	<i>Bacillus</i> sp., <i>L. fermentum</i> , <i>Leuc. mesenteroides</i> , <i>Streptococcus faecalis</i> , yeast	Breakfast or snack food	[16]
<i>Idli</i>	Black gram	India, Sri Lanka	<i>L. delbrueckii</i> , <i>L. fermentum</i> , <i>Lactococcus lactis</i> , <i>Leuc. mesenteroides</i> , <i>Strep. lactic</i> , <i>Ped. cerevisiae</i> , yeast	Breakfast food	[16]
<i>Khaman</i>	Bengal gram dhal or Chickpeas	India	<i>Bacillus</i> sp., <i>L. fermentum</i> , <i>Leuc. mesenteroides</i> , <i>Lact. lactis</i> , <i>Ped. acidilactici</i>	Snack	[33, 36, 37]
<i>Maseura</i>	Black gram	Nepal, India	<i>B. laterosporus</i> , <i>B. mycoides</i> , <i>B. pumilus</i> , <i>B. subtilis</i> , <i>C. castellii</i> , <i>Ent. durans</i> , <i>Ped. acidilactici</i> , <i>Ped. pentosaceus</i> , <i>L. fermentum</i> , <i>L. salivarius</i> , <i>S. cerevisiae</i> , <i>Pichia burtonii</i>	Dry, ball like, brittle, condiment	[38]
<i>Mashbari</i>	Black gram, spices	India	<i>Bacillus</i> sp. A ₉₄ , <i>Lactobacillus</i> sp., <i>S. cerevisiae</i>	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	<i>Aspergillus niger</i> , <i>C. versatilis</i> , <i>Cladosporium</i> sp., <i>Lactobacillus</i> sp., <i>Ped. acidilactici</i> , <i>Ped. pentosaceus</i> , <i>S. cerevisiae</i> , <i>Penicillium</i> sp.	Side dish	[40, 41]
Papad	Bengal gram, black gram, lentil, red or green gram	India	<i>C. krusei</i> , <i>S. cerevisiae</i> .	Condiment or savory food	[27, 37]
Probiotic food	Mung bean	China	<i>L. plantarum</i> B1-6	Beverage	[6]
Sepubari	Black gram, dangal, spices	India	<i>Bacillus</i> sp. A ₃₁ , <i>Lactobacillus</i> sp., <i>S. cerevisiae</i>	Special dish in marriage feast	[39]
Teliye mah	Black gram	India	NR	Semi solid	[29]
Tempeh	Chickpeas, local pulses	Indonesia, New Guinea, Surinam	<i>Asp. oryzae</i> , <i>Rhiz. oligosporus</i>	Breakfast food or snack	[16]
Tempe Benguk	Velvet bean seeds	Indonesia	<i>Rhiz. arrhizus</i> , <i>Rhiz. oligosporus</i>	Alkaline, solid, fried cake/ breakfast food	[42]
Tempe Kecipir	Winged bean seed	Indonesia	<i>Rhiz. achlamydosporus</i> , <i>Rhiz. arrhizus</i> , <i>Rhiz. oligosporus</i> , <i>Rhiz. oryzae</i>	Alkaline, solid, fried cake/ breakfast food	[43]
Tempe Koro Pedang	Jack bean seed	Indonesia	<i>Rhiz. achlamydosporus</i> , <i>Rhiz. arrhizus</i> , <i>Rhiz. oryzae</i>	Alkaline, solid, fried cake/ breakfast food	[43]
Vadai	Black gram	India	<i>Leuconostoc</i> sp., <i>Pediococcus</i> sp., <i>Streptococcus</i> sp.	Paste, side dish	[34]
Wadi	Black gram and oil	India	<i>L. fermentum</i> , <i>L. mesenteroides</i>	Spicy condiment or an adjunct for cooking vegetables or rice	[27, 44]
Wari	Bengal gram or Black gram	India, Pakistan	<i>B. subtilis</i> , <i>Candida</i> sp., <i>Cryptococcus humicolus</i> , <i>Debaryomyces</i> sp., <i>Ent. faecalis</i> , <i>G. candidum</i> , <i>H. anomala</i> , <i>Kl. marxianus</i> , <i>L. bulgaricus</i> , <i>S. cerevisiae</i> , <i>Strep. thermophiles</i> , <i>Trich beigelii</i> , <i>Win. robotsii</i>	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 Bowman-Birk 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 hand 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.

Author details

Oluwafemi Ayodeji Adebo^{1*}, Patrick Berka Njobeh¹, Janet Adeyinka Adebisi¹, Sefater Gbashi¹, Judith Zanele Phoku² and Eugenie Kayitesi^{1*}

*Address all correspondence to: oluwafemiadebo@gmail.com and eugeniek@uj.ac.za

1 Department of Biotechnology and Food Technology, University of Johannesburg, Johannesburg, Gauteng, South Africa

2 Water and Health Research Unit, University of Johannesburg, Johannesburg, Gauteng, South Africa

References

- [1] FAO International Year of Pulses 2016 [Internet]. 2016. Available from: www.fao.org/pulses-2016/en/ [Accessed: December 20, 2016]
- [2] Hu FB. Plant-based foods and prevention of cardiovascular disease: An overview. *American Journal of Clinical Nutrition*. 2003;**78**:544-551
- [3] Jay JM, Loessner MJ, Golden DA. *Modern Food Microbiology*. 7th ed. India: Springer; 2005. DOI: 10.1007/b100840
- [4] Galati A, Oguntotinbo FA, Moschetti G, Crescimanno M, Settanni L. The cereal market and the role of fermentation in cereal-based food production in Africa. *Food Reviews International*. 2014;**30**:317-337. DOI: 10.1080/87559129.2014.929143
- [5] Adebisi JA, Obadina AO, Adebo OA, Kayitesi E. Fermented and malted millet products in Africa: Expedition from traditional/ethnic foods to industrial value added products. *Critical Reviews in Food Science and Nutrition*. 2016. DOI: 10.1080/10408398.2016.1188056
- [6] Wu H, Rui X, Li W, Chen X, Jiang M, Dong M. Mung bean (*Vigna radiata*) as probiotic food through fermentation with *Lactobacillus plantarum* B1-6. *LWT-Food Science and Technology*. 2015;**63**:445-451. DOI: 10.1016/j.lwt.2015.03.011
- [7] Campos-Vega R, Loarca-Pina G, Oomah BD. Minor components of pulses and their potential impact on human health. *Food Research International*. 2010;**43**:461-482. DOI: 10.1016/j.foodres.2009.09.004
- [8] Tsao R, Yu L, Shahidi F. Cereals and pulses—An overview. In: Yu L, Tsao R, Shadidi F, editors. *Cereals and Pulses: Nutraceutical Properties and Health Benefits*. London, UK: Wiley; 2012. pp. 1-6. DOI: 10.1002/9781118229415.ch13
- [9] Tiwari BK, Gowen A, McKenna B. Pulses: What are they? In: Tiwari BK, Gowen A, McKenna B, editors. *Pulse Foods: Processing, Quality and Nutraceutical Applications*. London, UK: Academic Press; 2011. pp. 1-8.
- [10] FAOSTAT Food and Agriculture Organization Statistics [Internet]. 2016. Available from: www.fao.org/faostat/en/#home [Accessed: December 20, 2016]
- [11] Perez-Hidalgo MA, Guerra-Hernandez E, Garcia-Villanova B. Dietary fiber in three raw legumes and processing effect on chick peas by an enzymatic gravimetric method. *Journal of Food Composition and Analysis*. 1997;**10**:66-72. DOI: 10.1006/jfca.1997.0522
- [12] Sathe SK. Dry bean protein functionality. *Critical Reviews in Biotechnology*. 2002;**22**:175-223. DOI: 10.1080/07388550290789487
- [13] Kutos T, Golob T, Kac M, Plestenjak A. Dietary fiber of dry processed beans. *Food Chemistry*. 2002;**80**:231-235. DOI: 10.1016/S0308-8146(02)00258-3

- [14] Osorio-Diaz P, Bello-Perez LA, Sayago-Ayerdi SG, del Pilar Benitez-Reyes M, Tovar J, Paredes-Lopez O. Effect of processing and storage time on in vitro digestibility and resistant starch content of two bean (*Phaseolus vulgaris*) varieties. *Journal of the Science of Food and Agriculture*. 2003;**83**:1283-1288. DOI: 10.1002/jsfa.1413
- [15] Wang N, Toews N. Certain physicochemical and functional properties of fibre fractions from pulses. *Food Research International*. 2011;**44**:2515-2523. DOI: 10.1016/j.foodres.2011.03.012
- [16] Fraix J, Penas E, Martinez-Villaluenga C. Fermented pulses in nutrition and health promotion. In: Frias J, Martinez-Villaluenga C, Penas E, editors. *Fermented Foods in Health and Disease Prevention*. Academic Press; Rome, Italy: Food and Agriculture Organization of the United Nations. 2016. pp. 385-416. DOI: 10.1016/B978-0-12-802309-9.00016-9
- [17] FAO Cereals, pulses, legumes and vegetable proteins. [Internet]. 2007. Available from: www.fao.org/3/a-a1392e.pdf [Accessed: February 1, 2017]
- [18] Rehman ZU, Salariya AM, Zafar SI. Effect of processing on available carbohydrate content and starch digestibility of kidney beans (*Phaseolus vulgaris* L.). *Food Chemistry*. 2001;**73**:351-355. DOI: 10.1016/S0308-8146(00)00311-3
- [19] Benouis K. Phytochemicals and bioactive compounds of pulses and their impact on health. *Chemistry International*. 2017;**3**:224-229.
- [20] Singh J, Basu PS. Non-nutritive bioactive compounds in pulses and their impact on human health: An overview. *Food and Nutrition Sciences*. 2012;**3**:1664-1672. DOI: 10.4236/fns.2012.312218
- [21] United States Department of Agriculture Food Composition Database. [Internet]. Available from www.nal.usda.gov/fnic/foodcomp/search/ [Accessed: January 19, 2017]
- [22] Roy A, Moktan B, Sarkar PK. Traditional technology in preparing legume-based fermented foods of Orissa. *Indian Journal of Traditional Knowledge*. 2006;**6**:12-16.
- [23] Mugendi JB, Njagi ENM, Kuria EN, Mwasaru MA, Mureithi JG, Apostolides Z. Effects of processing technique on the nutritional composition and anti-nutrient content of mucuna bean (*Mucuna pruriens* L.). *African Journal of Food Science*. 2010;**4**:156-166
- [24] Satish KR, Kanmani P, Yuvaraj N, Paari KA, Pattukumar V, Arul V. Traditional Indian fermented foods: A rich source of lactic acid bacteria. *International Journal of Food Science and Nutrition*. 2013;**64**:415-428. DOI: 10.3109/09637486.2012.746288.
- [25] Tamang JP, Sarkar PK, Hesseltine CW. Traditional fermented foods and beverages of Darjeeling and Sikkim—A review. *Journal of the Science of Food and Agriculture*. 1988;**44**:375-385. DOI: 10.1002/jsfa.2740440410
- [26] Ross RP, Morgan S, Hill C. Preservation and fermentation: past, present and future. *International Journal of Food Microbiology*. 2002;**79**:3-16. DOI: 10.1016/S0168-1605(02)00174-5

- [27] Aidoo KE, Nout NJR, Sarkar PK. Occurrence and function of yeasts in Asian indigenous fermented foods. *FEMS Yeast Research*. 2006;**1**:30-39. DOI: 10.1111/j.1567-1364.2005.00015.x
- [28] Steinkraus KH. *Handbook of Indigenous Fermented Foods*. 2nd ed. New York: Marcel Dekker; 1996
- [29] Thakur N, Savitri, Bhalla TC. Characterization of some traditional fermented foods and beverages of Himachal Pradesh. *Indian Journal of Traditional Knowledge*. 2004;**3**:325-335
- [30] Rani DK, Soni SK. Applications and commercial uses of microorganisms. In: Soni SK, editor. *Microbes: A Source of Energy for 21st Century*. Tohtas Nagar, Shahdara, Delhi: Jai Bharat Printing Press; 2011:71-126
- [31] Oboh G. Nutrient and antinutrient composition of condiments produced from some fermented underutilized legumes. *Journal of Food Biochemistry*. 2006;**30**:576-588. DOI: 10.1111/j.1745-4514.2006.00083.x
- [32] Sha SP, Ghatani K, Tamang JP. *Dalbari*, a traditional pulses based fermented food of West Bangal. *International Journal of Agriculture and Food Science and Technology*. 2013;**4**:6-10
- [33] Joshi N, Godbole SH, Kanekar P. Microbial and biochemical changes during *dhokla* fermentation with special reference to flavour compounds. *Journal of Food Science and Technology*. 1989;**26**:113-115
- [34] Blandino A, Al-Aseeri ME, Pandiella SS, Contero D, Webb C. Cereal based fermented foods and beverages. *Food Research International*. 2003;**36**:527-543. DOI:10.1016/S0963-9969(03)00009-7
- [35] Roy A, Moktan B, Sarkar PK. Survival and growth of foodborne bacterial pathogens in fermenting batter of *dhokla*. *Journal of Food Science and Technology*. 2009;**46**:132-135.
- [36] Ramakrishnan CV. Studies on Indian fermented foods. *Baroda Journal of Nutrition*. 1979;**6**: 1-54
- [37] Roy A, Moktan B, Sarkar PK. Traditional technology in preparing legume based fermented foods of Orissa. *Indian Journal of Traditional Knowledge*. 2007;**1**:12-16
- [38] Chettri R, Tamang JP. Microbiological evaluation of *maseura*, an ethnic fermented legume-based condiment of Sikkim. *Journal of Hill Research*. 2008;**21**:1-7
- [39] Sharma N, Handa S, Gupta A. A comprehensive study of different traditional fermented foods/beverages of Himachal Pradesh to evaluate their nutrition impact on health and rich biodiversity of fermenting microorganisms. *International Journal of Research in Applied, Natural and Social Sciences*. 2013;**3**:19-28
- [40] Dahal NR, Karki TB, Swamylingappa B, Li Q, Gu G. Traditional foods and beverages of Nepal—A review. *Food Review international*. 2005;**21**:1-25. DOI: 10.1081/FRI-200040579
- [41] Dahal NR, Rao ER, Swamylingappa B. Biochemical and nutritional evaluation of *Masyaura*-a legume based traditional savory of Nepal. *Journal of Food Science and Technology*. 2003;**1**:17-22

- [42] Nagai T, Tamang JP. Fermented soybeans and non-soybeans legume foods. In: Tamang JP, Kailasapathy K. editors. *Fermented Foods and Beverages of the World*. New York: CRC Press, Taylor and Francis Group; 2010. pp. 191-224
- [43] Alexandraki V, Tsakalidou E, Papadimitriou K, Holzapfel WH. Status and Trends of the Conservation and Sustainable Use of Microorganisms in Food Processes. Commission on Genetic Resources for Food and Agriculture. FAO Background Study. London, UK 2013;65.
- [44] Sandhu DK, Soni SK. Microflora associated with Indian Punjabi *warri* fermentation. *Journal of Food Science and Technology*. 1989;**26**:21-25
- [45] Tewary HK, Muller HG. The fate of some oligosaccharides during the preparation of *wari*, an Indian fermented food. *Food Chemistry*. 1992;**2**:107-111. DOI: 10.1016/0308-8146(92)90222-N
- [46] Kulkarni SG, Manan JK, Agarwal MD, Shukla IC. Studies on physico-chemical composition, packaging and storage of black gram and green gram Wari prepared in Uttar Pradesh. *Journal of Food Science and Technology*. 1997;**2**:119-122
- [47] Bonar A. Functional Foods Market Is Expected to Grow 25% by 2017: Leatherhead [Internet]. 2014. Available from <http://www.nutraingredients.com/Markets-and-Trends/Functional-foods-market-is-expected-to-grow-25-by-2017-Leatherhead> [Accessed: January 31, 2017]
- [48] Granito M, Frias J, Doblado R, Guerra M, Champ M, Vidal-Valverde C. Nutritional improvement of beans (*Phaseolus vulgaris*) by natural fermentation. *European Food Research and Technology*. 2002;**214**:226-231. DOI: 10.1007/s00217-001-0450-5
- [49] Dueñas M, Hernández T, Estrella I. Occurrence of phenolic compounds in the seed coat and the cotyledon of peas (*Pisum sativum* L.). *European Food Research and Technology*. 2004;**219**:116-123. DOI: 10.1007/s00217-004-0938-x
- [50] Pandey KB, Rizvi SI. Plant polyphenols as dietary antioxidants in human health and disease. *Oxidative Medicine and Cellular Longevity*. 2009;**5**:270-278. DOI: 10.4161/oxim.2.5.9498
- [51] Manach C, Scalbert A, Morand C, Rémésy C, Jiménez L. Polyphenols: Food sources and bioavailability. *The American Journal of Clinical Nutrition*. 2004;**79**:727-747
- [52] Ozcan T, Akpınar-Bayazit A, Yılmaz-Ersan L, Delikanlı B. Phenolics in human health. *International Journal of Chemical Engineering and Applications*. 2014;**5**:393-396. DOI: 10.7763/ijcea.2014.v5.416
- [53] Tharanathan RN, Mahadevamma S. Grain legumes a boon to human nutrition. *Trends in Food Science and Technology*. 2003;**14**:507-518. DOI: 10.1016/j.tifs.2003.07.002
- [54] Xu BJ, Chang SKC. A comparative study on phenolic profiles and antioxidant activities of legumes as affected by extraction solvents. *Journal of Food Science*. 2007;**72**:159-166. DOI: 10.1111/j.1750-3841.2006.00260.x

- [55] Oboh G, Ademiluyi AO, Akindahunsi AA. Changes in polyphenols distribution and antioxidant activity during fermentation of some underutilized legumes. *Food Science and Technology International*. 2009;**15**:41-46. DOI: 10.1177/1082013208101022
- [56] Ademiluyi AO, Oboh G. Soybean phenolic-rich extracts inhibit key-enzymes linked to type 2 diabetes (α -amylase and α -glucosidase) and hypertension (angiotensin I converting enzyme) *in vitro*. *Experimental and Toxicologic Pathology*. 2013;**65**:305-309. DOI: 10.1016/j.etp.2011.09.005
- [57] Ademiluyi AO, Oboh G, Boligon AA, Althayde ML. Dietary supplementation with fermented legumes modulate hyperglycemia and acetylcholinesterase activities in Streptozotocin-induced diabetes. *Pathophysiology*. 2015;**22**:195-201. DOI: 10.1016/j.pathophys.2015.08.003
- [58] Megías C, Cortés-Giraldo I, Alaiz M, Vioque J, Girón-Calle J. Isoflavones in chickpea (*Cicer arietinum*) protein concentrates. *Journal of Functional Foods*. 2016;**21**:186-192. DOI: 10.1016/j.jff.2015.12.012
- [59] Ho, CT. Phenolic compounds in food. In Ho C, Lee CY, & Huang M, editors. *Phenolic Compounds in Food and their Effects on Health I. Analysis, Occurrence and Chemistry*. Washington, DC: American Chemical Society. 1992. pp. 1-7
- [60] Frassinetti S, Gabriele M, Caltavuturo L, Longo V, Pucci L. Antimutagenic and antioxidant activity of a selected lectin-free common bean (*Phaseolus vulgaris* L.) in two cell-based models. *Plant Foods for Human Nutrition*. 2015;**70**:35-41. DOI: 10.1007/s11130-014-0453-6
- [61] Moktan B, Roy A, Sarkar PK. Antioxidant activities of cereal-legume mixed batters as influenced by process parameters during preparation of *dhokla* and *idli*, traditional steamed pancakes. *International Journal of Food Sciences and Nutrition*. 2011;**62**:360-369. DOI: 10.3109/09637486.2010.532116
- [62] Yeap SK, Beh BK, Ho YW, Yusof HM, Mohamad NE, Ali NM, Jaganath IB, Alitheen NB, Koh SP, Long K. *In vivo* antioxidant and hypolipidemic effects of fermented mung bean on hypercholesterolemic mice. *Evidence-Based Complementary and Alternative Medicine*. 2015:1-6. DOI: 10.1155/2015/508029
- [63] Scalbert A, Manach C, Morand C, Remesy C. Dietary polyphenols and the prevention of diseases. *Critical Reviews in Food Science and Nutrition*. 2005;**45**:287-306. DOI: 10.1080/1040869059096
- [64] Arts ICW, Hollman PCH. Polyphenols and disease risk in epidemiologic studies. *American Journal of Clinical Nutrition*. 2005;**81**:317-325
- [65] Anderson JW, Major AW. Pulses and lipaemia, short- and long-term effect: Potential in the prevention of cardiovascular disease. *British Journal of Nutrition*. 2002;**88**:263-271. DOI: 10.1079/BJN2002716
- [66] McCrory MA, Hamaker BR, Lovejoy JC, Eichelsdoerfer PE. Pulse consumption, satiety, and weight management. *Advances in Nutrition*. 2010;**1**:17-30. DOI: 10.3945/an.110.1006

- [67] Agurs-Collins T, Smoot D, Afful J, Makambi K, Adams-Campbell LL. Legume intake and reduced colorectal adenoma risk in African-Americans. *Journal of National Black Nurses Association*. 2007;**17**(2):6-12
- [68] Villegas R, Gao Y-T, Yang G, Li H-L, Elsay TA, Zheng W, Shu XO. Legume and soy food intake and the incidence of type 2 diabetes in the Shanghai Women's Health Study. *American Journal of Clinical Nutrition*. 2008;**87**:162-167
- [69] Bartolomé B, Estrella I, Hernandez T. Changes in phenolic compounds in lentils (*Lens culinaris*) during germination and fermentation. *Zeitschrift fur Lebensmitteluntersuchung und-Forschung A*. 1997;**205**:290-294. DOI: 10.1007/s002170050167
- [70] Oboh G, Rocha JBT. Polyphenols in red pepper (*Capsicum annum* var aviculare Tepin) and their protective effects on some pro-oxidant induced lipid peroxidation in brain and liver. *European Food Research and Technology*. 2007;**225**:239-247. DOI: 10.1007/s00217-006-0410-1
- [71] Jiménez N, Esteban-Torres M, Mancheno JM, De Las eivas B, Munoz R. Tannin degradation by a novel tannase enzyme present in some *Lactobacillus plantarum* strains. *Applied and Environmental Microbiology*. 2014;**80**:2991-2997. DOI: 10.1128/AEM.00324-14
- [72] Limon RI, Penas E, Torin MI, Martinez-Villaluenga C, Frias J. Fermentation enhances the content of bioactive compounds in kidney bean extracts. *Food Chemistry*. 2015;**172**:343-352. DOI: 10.1016/j.foodchem.2014.09.084
- [73] Esteban-Torres M, Landete JM, Reveron I, Santamaria L, de las Rivas B, Munoz R. A *Lactobacillus plantarum* esterase active on a board range of phenolic esters. *Applied and Environmental Microbiology*. 2015;**81**:3235-3242. DOI: 10.1128/AEM.00323-15
- [74] Vasconcelos IK, Oliveria JTA. Antinutritional proprieties of plant lectins. *Toxicon*. 2004;**44**:385-403. DOI: 10.1016/j.toxicon.2004.05.005
- [75] Boye J, Zare F, Pletch A. Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International*. 2010;**43**:414-431. DOI: 10.1016/j.foodres.2009.09.003
- [76] Belitz HD, Weder JKP. Protein inhibitors of hydrolases in plants foodstuffs. *Food Reviews International*. 1990;**6**:151-211. DOI: 10.1080/87559129009540866
- [77] Chen YW, Huang SC, Shiau SYL, Lin JK. Bowman –Birk inhibitor abates proteosome function and suppresses the proliferation of MCF7 breast cancer cells through accumulation of MAP kinase phosphatase-1. *Carcinogenesis*. 2005;**26**:1296-1306. DOI: 10.1093/carcin/bgi062
- [78] Clemente A, Gee JM, Johnson IT, Mackenzie DA, Domoney C. Pea (*Pisum sativum*) protease inhibitors from the Bowman-Birk class influence the growth of human colorectal adenocarcinoma HT29 cells *in vitro*. *Journal of Agriculture Food Chemistry*. 2005;**53**:8979-8986. DOI: 10.1021/jf051528w

- [79] Clemente A, Domoney C. Biological significance of polymorphism in legume protease inhibitors from the Bowman—Birk family. *Current Protein and Peptide Science*. 2006;**7**:201-216. DOI: 10.2174/138920306777452349
- [80] Duranti M. Grain legume proteins and nutraceutical properties. *Fitoterapia*. 2006;**77**:67-82. DOI: 10.1016/j.fitote.2005.11.008
- [81] Clemente A, Arques MDC. Bowman-Birk inhibitors from legumes as colorectal chemoprotective agents. *World Journal of Gastroenterology*. 2014;**20**:10305-10315. DOI: 10.3748/wjg.v20.i30.10305
- [82] Cuadrado C, Hajos G, Burbano C, Pedrosa MM, Ayet G, Muzquiz M, Pusztai A, Gelencser E. Effect of natural fermentation on the lectin of lentils measured by immunological methods. *Food and Agricultural Immunology*. 2002;**14**:41-49. DOI: 10.1080/09540100220137655
- [83] Klupšaitė D, Juodeikienė G. Legume: Composition, protein extraction and functional properties. A review. *Chemical Technology*. 2015;**66**:5-12. DOI: 10.5755/j01.ct.66.1.12355
- [84] Hamid R, Masood A, Wani IH, Rafiq S. Lectins: Proteins with diverse applications. *Journal of Applied Pharmaceutical Science*. 2013;**3**:93-103. DOI: 10.7324/JAPS.2013.34.S18
- [85] Khan FA, Khan A, Khattak MUR, Ullah N, Zahoor M, Shah SMM. Evaluation of inorganic profile and anti-nutritional values of *Cocculus hirsutus*. *African Journal of Pharmacy and Pharmacology*. 2012;**6**:144-147. DOI: 10.5897/ajpp11.410
- [86] Hurrell RF, Reddy M, Cook JD. Inhibition of non-haem iron absorption in man by polyphenolic-containing beverages. *British Journal of Nutrition*. 1999;**81**:289-295
- [87] Hanakahi LA, Bartlett-Jones M, Chappell C, Pappin D, West SC. Binding of inositol phosphate to DNA-PK and stimulation of double-strand break repair. *Cell*. 2000;**102**:721-729. DOI: 10.1016/s0092-8674(00)00061-1
- [88] Shamsuddin AM. Anti-cancer function of phytic acid. *International Journal of Food Science and Technology*. 2002;**37**:769-782. DOI: 10.1046/j.1365-2621.2002.00620.x
- [89] Minihihi AM, Rimbach G. Iron absorption and the iron binding and anti-oxidant properties of phytic acid. *International Journal of Food Science and Technology*. 2002;**37**:741-748. DOI: 10.1046/j.1365-2621.2002.00619.x
- [90] Kingsley O, Marshall AA. Medicinal potential of *Acalypha wilkesiana* leaves. *Advances in Research*. 2014;**2**:655-665. DOI: 10.9734/air/2014/9452
- [91] Shears SB. Assessing the omnipotence of inositol hexakisphosphate. *Cell Signalling*. 2001;**13**:151-158. DOI: 10.1016/s0898-6568(01)00129-2
- [92] Coda R, Melama L, Rizzello CG, Curiel JA, Sibakov J, Holopainen U, Pulkkinen M, Sozer N. Effect of air classification and fermentation by *Lactobacillus plantarum* VTT E-133328 on faba bean (*Vicia faba* L.) flour nutritional properties. *International Journal of Food Microbiology*. 2015;**193**:34-42. DOI: 10.1016/j.ijfoodmicro.2014.10.012

- [93] Akpapunam MA, Achinewhu SC. Effects of cooking, germination and fermentation on the chemical composition of Nigerian cowpea (*Vigna unguiculata*). *Plant Foods for Human Nutrition*. 1985;**35**:353-358. DOI: 10.1007/BF01091780
- [94] Khattab RY, Arntfield SD. Nutritional quality of legume seeds as affected by some physical treatments 2. Antinutritional factors. *LWT-Food Science and Technology*. 2009;**42**:1113-1118. DOI: 10.1016/j.lwt.2009.02.004
- [95] Reddy NR, Pierson MD. Reduction in antinutritional and toxic components in plant foods by fermentation. *Food Research International*. 1994;**27**:281-290. DOI: 10.1016/0963-9969(94)90096-5
- [96] Sandberg AS, Andlid T. Phytogenic and microbial phytases in human nutrition. *International Journal of Food Science and Technology*. 2002;**37**:823-833. DOI: 10.1046/j.1365-2621.2002.00641.x
- [97] Tosh SM, Yada S. Dietary fibres in pulse seeds and fractions: Characterization, functional attributes, and applications. *Food Research International*. 2010;**43**:450-460. DOI: 10.1016/j.foodres.2009.09.005
- [98] Van Horn L. Fibre, lipids, and coronary heart disease. A statement for healthcare professionals from the nutrition committee, American Heart Association. *Circulation*. 1997;**95**:2701-2704. DOI: 10.1161/01.cir.95.12.2701
- [99] Annor GA, Ma Z, Boye JI. Crops—legumes. In: Clark S, Jung S, Lamsal B, editors. *Food Processing: Principles and Applications*. 2nd ed. Chichester: John Wiley and Sons Ltd; 2014. pp. 305-337
- [100] Fardet A. New hypotheses for the health-protective mechanisms of whole-grain cereals: What is beyond fibre? *Nutrition Research Reviews*. 2010;**23**:65-134. DOI: 10.1017/S0954422410000041
- [101] Marlett JA, McBurney MI, Slavin JL. Position of the American Dietetic Association: Health implications of dietary fiber. *Journal of the American Dietetic Association*. 2002;**102**:993-1000. DOI: 10.1016/s0002-8223(02)90228-2
- [102] Glore SR, Van Treeck D, Knehans AW, Guild M. Soluble fiber and serum lipids: A literature review. *Journal of the American Dietetic Association*. 1994;**94**:425-436. DOI: 10.1016/0002-8223(94)90099-x
- [103] Hoover R, Hughes T, Chung HJ, Liu Q. Composition, molecular structure, properties, and modification of pulse starches: A review. 2010;**43**:399-413. DOI: 10.7324/JAPS.2013.34.S18
- [104] Lehmann U, Robin F. Slowly digestible starch- its structure and health implications: A review. *Trends in Food Science and Technology*. 2007;**18**:346-355. DOI: 10.1016/j.tifs.2009.12.001

- [105] Veena A, Urooj A, Puttaraj S. Effect of processing on the composition of dietary fibre and starch in some legumes. *Molecular Nutrition and Food Research*. 1995;**39**:132-138. DOI: 10.1002/food.19950390206
- [106] Kavita V, Verghese S, Chitra GR, Prakash J. Effects of processing time, storage temperature on the resistant starch of foods. *Journal of Food Science and Technology*. 1998;**35**:299-304
- [107] Granito M, Alvarez G. Lactic acid fermentation of black beans (*Phaseolus vulgaris*): Microbiological and chemical characterization. *Journal of the Science of Food and Agriculture*. 2006;**86**:1164-1171. DOI: 10.1002/jsfa.2490
- [108] Guillon F, Champ MM. Carbohydrate fractions of legumes: Uses in human nutrition and potential for health. *British Journal of Nutrition*. 2002;**88**:293-306. DOI: 10.1079/bjn2002720
- [109] Dilawari J, Kumar V, Bhatnagar R, Dash R. Effect of legumes on blood sugar in diabetes mellitus. *Indian Journal of Medical Research*. 1987;**85**:184-187
- [110] Jenkins DJA, Wolever T, Jenkins AL. Starchy foods and glycemic index. *Diabetes Care*. 1988;**11**:149-159. DOI: 10.2337/diacare.11.2.149
- [111] Messina MJ. Legumes and soybeans: overview of their nutritional profiles and health effects. *The American Journal of Clinical Nutrition*. 1999;**70**:439-450
- [112] Luo J, Yperselle MV, Rizkalla SW, Rossi F, Bornet FJR, Slama G. Chronic consumption of short-chain fructooligosaccharides does not affect basal hepatic glucose production or insulin resistance in type 2 diabetes. *Journal of Nutrition*. 2000;**130**:1572-1577
- [113] Atkinson FS, Foster-Powell K, Brand-Miller JC. International tables of glycemic index and glycemic load values: 2008. *Diabetes Care*. 2008;**31**:2281-2283. DOI: 10.2337/dc08-1239
- [114] Yeap SK, Ali NM, Yusof HM, Alitheen NB, Beh BK, Ho WY, Koh SP, Long K. Anti-hyperglycemic effects of fermented and nonfermented mung bean extracts on alloxan-induced-diabetic mice. *Journal of Biomedicine and Biotechnology*. 2012;1-7. DOI: 10.1155/2012/285430
- [115] Liu S, Stampfer M, Hu F, Giovannucci E, Rimm E, Manson J, Hennekens C, Willett W. Whole-grain consumption and risk of coronary heart disease: results from the Nurses' Health Study. *American Journal of Clinical Nutrition*. 1999;**70**:412-419
- [116] Patterson CA, Maskus H, Dupasquier C. Pulse crops for health. *Cereal Foods World*. 2009;**54**:108-112
- [117] Vidal-Valverde C, Frias J, Prodanov M, Tabera J, Ruiz R, Bacon J. Effect of natural fermentation on carbohydrates, riboflavin and trypsin inhibitor activity of lentils. *Zeitschrift fur Lebensmittel-Untersuchung und -Forschung*. 1993;**197**:449-452. DOI: 10.1007/BF01202616

- [118] Yadav S, Khetarpaul N. Indigenous fermentation: effect on some antinutrients and *in-vitro* digestibility of starch and protein. Food Chemistry. 1993;**50**:403-406. DOI: 10.1016/0308-8146(94)90213-5
- [119] Bhandal A. Effect of fermentation on *in vitro* digestibilities and the level of antinutrients in moth bean [*Vigna aconitifolia* (Jacq.) Marechal]. International Journal of Food Science and Technology. 2008;**43**:2090-2094. DOI: 10.1111/j.1365-2621.2008.01827.x
- [120] Egounlety M, Aworh OC. Effect of soaking, dehulling, cooking and fermentation with *Rhizopus oligosporus* on the oligosaccharides, trypsin inhibitor, phytic acid and tannins of soybean (*Glycine max* Merr.), cowpea (*Vigna unguiculata* L. Walp) and ground-bean (*Macrotyloma geocarpa* Harms). Journal of Food Engineering. 2003;**56**:249-254. DOI: 10.1016/S0260-8774(02)00262-5
- [121] Adewumi GA, Odunfa SA. Effect of controlled fermentation on the oligosaccharides content of two common Nigerian *Vigna unguiculata* beans (*drum* and *oloyin*). African Journal of Biotechnology. 2009;**8**:2626-2630
- [122] Odunfa SA. Carbohydrate changes in fermenting locust bean (*Parkia filicoidea*) during iru preparation. Plant Foods for Human Nutrition. 1983;**32**:3-10. DOI: 10.1007/bf01093924
- [123] Roy F, Boye JI, Simpson BK. Bioactive proteins and peptides in pulse crops: Pea, chickpea and lentil. Food Research International. 2010;**43**:432-442. DOI: 10.1016/j.foodres.2009.09.002
- [124] Sotelo A, Adsule RN. Chickpea. In: Nwokolo E, Smartt J, editors. Food and Feed from Legumes and Oilseeds. London, UK: Chapman and Hall; 1996. pp. 82-89
- [125] Duranti M, Gius C. Legume seeds: Protein content and nutritional value. Field Crops Research. 1997;**53**:31-45. DOI: 10.1016/s0378-4290(97)00021-x
- [126] Farrokhi N, Whitelegge JP, Brusslan JA. Plant peptides and peptidomics. Plant Biotechnology Journal. 2008;**6**:105-134. DOI: 10.1111/j.1467-7652.2007.00315.x
- [127] Malaguti M, Dinelli G, Leoncini E, Bregola V, Bosi S, Cicero AFG, Hrelia S. Bioactive peptides in cereals and legumes: Agronomical, biochemical and clinical aspects. International Journal of Molecular Sciences. 2014;**15**:21120-21135. DOI: 10.3390/ijms151121120
- [128] Coda R, Rizzello CG, Pinto D, Gobbetti M. Selected lactic acid bacteria synthesize antioxidant peptides during sourdough fermentation of cereal flours. Applied and Environmental Microbiology. 2011;**78**:1087-1096. DOI: 10.1128/aem.06837-11
- [129] Sanjeewa WGT, Wanasundara JPD, Pietrasik Z, Shand PJ. Characterization of chickpea (*Cicer arietinum* L.) flours and application in low-fat pork bologna as a model system. Food Research International. 2010;**43**:617-626. DOI: 10.1016/j.foodres.2009.07.024
- [130] Cabuk B, Korber D, Tanaka T, Nickerson M. [Internet]. Fermenting Pulses for Improved Nutrition and Functionality 2016. Available from: <http://canadianfoodbusiness.com/2016/06/20/fermenting-pulses-for-improved-nutrition-and-functionality/> [Accessed: January 24, 2017]

- [131] Zambrowicz A, Timmer M, Polanowski A, Lubec G, Trziszka T. Manufacturing of peptides exhibiting biological activity. *Amino Acids*. 2012;**44**:315-320. DOI: 10.1007/s00726-012-1379-7
- [132] Tavano OL. Protein hydrolysis using proteases: An important tool for food biotechnology. *Journal of Molecular Catalysis B*. 2013;**90**:1-11. DOI: 10.1016/j.molcatb.2013.01.011
- [133] Xiao Y, Xing, G, Rui X, Li W, Chen X, Jiang M, Dong M. Effect of solid-state fermentation with *Cordyceps militaris* SN-18 on physicochemical and functional properties of chickpea (*Cicer arietinum* L.) flour. *LWT-Food Science and Technology*. 2015;**63**:1317-1324. DOI: 10.1016/j.lwt.2015.04.046
- [134] Lee IH, Hung YH, Chou CC. Solid-state fermentation with fungi to enhance the anti-oxidative activity, total phenolic and anthocyanin contents of black bean. *International Journal of Food Microbiology*. 2008;**121**:150-156. DOI: 10.1016/j.ijfoodmicro.2007.09.008
- [135] Jung S, Murphy PA, Johnson LA. Physicochemical and functional properties of soy protein substrates modified by low levels of protease hydrolysis. *Journal of Food Science*. 2005;**70**:180-187. DOI: 10.1111/j.1365-2621.2005.tb07080.x
- [136] Reddy NR, Pierson MD, Sathe SK, Salunkhe DK. Legume-based fermented foods: Their preparation and nutritional quality. *Critical Review in Food Science and Nutrition*. 1982;**17**:335-370. DOI: 10.1080/10408398209527353
- [137] Prasad SK, Singh MK. Horse gram- an underutilized nutraceutical pulse crop: A review. *Journal of Food Science and Technology*. 2015;**52**:2489-2499. DOI: 10.1007/s13197-014-1312-z
- [138] Faris MAE, Attlee A. Lentils (*Lens culinaris* L.): a novel functional food. In: Shekhar HU, Howlader ZH, Kabir Y, editors. *Exploring the Nutrition and Health Benefits of Functional Foods*, USA: ICI Global; 2017. pp. 42-72. DOI: 10.4018/978-1-5225-0591-4.ch003
- [139] Bazzano LA, He J, Ogden LG, Loria C, Vupputuri S, Myers L, Whelton PK. Dietary potassium intake and risk of stroke in us men and women: National health and nutrition examination survey I epidemiologic follow-up study. *Stroke*. 2001;**32**:1473-1480. DOI: 10.1161/01.str.32.7.1473
- [140] Lee JW, Shin JG, Kim EH, Kang HE, Yim IB, Kim JY, Joo HG, Woo HJ. Immunomodulatory and antitumor effects in vivo by the cytoplasmic fraction of *Lactobacillus casei* and *Bifidobacterium longum*. *Journal of Veterinary Science*. 2004;**1**:41-48
- [141] Flight I, Clifton P. Cereal grains and legumes in the prevention of coronary heart disease and stroke : A review of the literature. *European Journal of Clinical Nutrition*. 2006;**60**:1145-1159. DOI: 10.1038/sj.ejcn.1602435
- [142] Kandasamy M, Bay BH, Lee YK. Lactobacilli secreting a tumor antigen and IL15 activates neutrophils and dendritic cells and generates cytotoxic T lymphocytes against cancer cells. *Cell Immunology*. 2011;**271**:89-96. DOI: 10.1016/j.cellimm.2011.06.004