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A review article on health benefits of Pigeon pea (*Cajanus cajan (L.) Millsp*)

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ABSTRACT

Pigeon pea is a perennial tropical crop primarily grown in Asia and Africa, and its seeds are consumed as a rich source of protein and carbohydrates both in fresh and dried forms. It has been used as an important part of the folk and traditional medicine in India, China, and South America to prevent and treat various human diseases.

This crop has been successfully grown in some southeastern states but still considered as a novel pulse here in the US with the majority of the work focused on its non-consumable parts like leaves, stems, and roots. Literature studies indicate that pigeon pea has the potential to prevent and treat many human diseases such as bronchitis, pneumonia, measles, hepatitis, yellow fever, ulcers, diabetes, and certain forms of cancer. Nutritionally along with protein and fiber, it has a decent number of health-promoting phytochemicals. Foremost phytochemicals found in pigeon pea seeds are phenolic acids, flavonoids, tannins, saponins, and phytic acid. These minor components predominately exhibit antioxidant, antidiabetic, and anti-inflammatory activities. It is an excellent source of inexpensive plant-based protein. Some studies describe the bioactive role of protein fractions, especially as an antihyperglycemic factor. Seeds are the edible and non-perishable part of this crop with the feasibility of addition in food products. Functional properties of the pigeon pea flour make it a suitable ingredient for food products like bread, pasta, and nutritional bars which can make it a gluten-free substitute for cereals.

Keywords: Pigeon pea, protein, fiber, phenolic acids, flavonoids, tannins, saponins, phytic acid, antioxidant, antidiabetic

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Introduction

Global food production is encountering challenges with growing population, biodiversity, water shortage, and climate change. With the rise of suburbanization, healthy diets are replaced with highly refined and processed one.

While one possible way to increase and conserve food availability is through shifting diets (Tilman & Clark, 2014). Incorporating a diet with manifold health benefits is a level approach to attain the nutritional needs along with health promotion and disease avoidance. There are evolving needs for healthy food products with multifold health benefits to meet consumers' budding demands for disease prevention and well-being. Therefore, the use of crops with multiple bioactive components is getting increased attention.

Pigeon pea (*Cajanus cajan (L) Millsp*) is a perennial crop of sub-tropical and tropical regions, originated in the northern region of Indian sub-continent. It is also known as red gram, congo pea, gungo pea, and no-eye pea which belongs to the family of Leguminosae (Wu et al., 2009). The slave trade was a source of taking it to Africa and South America. It is cultivated in 22 countries worldwide (FAO, 2008), but only a few countries with major productions. India, Myanmar, and Nepal are the foremost producers in Asia with India leading in the worldwide production of 2,584,007 tons as of 2014 (FAO, 2015). Kenya, Malawi, Uganda, Mozambique, and Tanzania are the primary producers of pigeon pea in Africa. Some South American countries like Brazil and the Caribbean islands also have equitable areas for its production. Average of production share from 2000 to 2015 in these three continents is, Asia 84.5%, Africa 13.4%, and Americas 2% (FAO, 2015). In the US, researchers at the University of Hawaii were among the earliest promoters in the state with a long tradition of cultivation (Valenzuela & Smith, 2002). Pigeon pea is one of the crops that can produce more nitrogen per unit of plant biomass than most other legumes (Onim, 1987). It is valuable legume that can tolerate dry weather and poor soil conditions, can grow well on marginal lands, and help with soil and water storage (Rao, Phillips, Mayeux, & Phatak, 2003). Pigeon pea is grown in tropical and subtropical regions which is tolerant to low and high temperatures (Nene, Hall, & Sheila, 1990). This crop ranks sixth in the world in dryland legume production (FAO, 2015). The National Research Council has recommended that this crop is grown widely in the United States as it is becoming a new marketable resource for small farms in the southeast states. Pigeon pea has been successfully grown in some southeastern state including Tennessee, Alabama, Virginia, Texas, and Georgia.

Pigeon pea is an important component of many people's diet in Asia, Africa and South America (Martínez-Villaluengaa, Torresb, Friasa, & Vidal-Valverde, 2010). It has been used to achieve the needs of food, forage, feed, and therapeutics. Conventional consumption of seed is as a green vegetable and dry pulse, but young green pods, shoots, and leaves are also edible. Bioactive components in pulse seeds are getting increased attention in recent years. Some review papers summarized major bioactive constituents including proteins (Boye, Zare, & Pletch, 2010), dietary fiber (Tosh & Yada, 2010), and the minor bioactive constituents (Campos-Vega, Oomah, Loarca-Piña, & Vergara-Castañeda, 2013). Different parts of the pigeon pea have been used as an important part of the folk and traditional medicine in India, China, and South America (Morton, 1976). Research studies demonstrate that Pigeon pea has potential to prevent and treat many human diseases such as bronchitis, pneumonia, measles, hepatitis, menstrual disorders, sores, yellow fever, ulcers, body aches, and certain forms of cancer (Saxena, Kumar, & Sultana, 2010). Pigeon pea (*Cajanus cajan* (L.) Millsp.) has revealed strong biological and pharmacological activities including anti-diabetic, anti-inflammatory, and anti-oxidant activities (Wu et al., 2009). Disease prevention and health advancement and can be attained by the introduction of this emerging crop in food applications. These goals can be achieved by fully understating the chemical, physical and biological properties of bioactive components in Pigeon pea and their health-promoting effect after integrating into food.

In the United States, very few studies about health-promoting effects through an increased dietary consumption of Pigeon pea are available. The knowledge on chemical, physical, functional properties of its major bioactive components, the feasibility of its application in food systems, and the health effects of preventing inflammation and promoting gastrointestinal health can fill these gaps.

Nutritional quality in pigeon pea seeds

Nutritionally Pigeon pea is a good source of protein, fiber, and minerals (Table 1) making it a good candidate for the production of protein and fiber-fortified foods. It is reported that fortified food is a major contributor to nutrient intakes in the diets of US children and adolescents.

Table 1. Distribution of Nutrients in Mature Seed of Pigeon Pea

Nutrient (g /100 g)	Mature Seed
Protein	21.7
Carbohydrates	62.78
Total dietary fiber	15
Total lipid	1.49
Minerals (mg / 100 g)	
Calcium, Ca	130
Iron, Fe	5.23
Magnesium, Mg	183
Phosphorus, P	367
Potassium, K	1392
Sodium, Na	17
Zinc, Zn	2.76
Vitamins (mg / 100 g)	
Vitamin C	0
Thiamin	0.643
Riboflavin	0.187
Niacin	2.965
Vitamin B-6	0.283
Amino acids (g /100 g)	
Tryptophan	0.212
Threonine	0.767
Isoleucine	0.785
Leucine	1.549
Lysine	1.521
Methionine	0.243
Cystine	0.25
Phenylalanine	1.858
Tyrosine	0.538

Source: USDA (2016)

Protein in Pigeon pea

Majority of the protein found within pulse seeds is in the form of storage proteins classified as globulins, albumins, and glutelins (Roy et al., 2010). Globulins make up about 65% of the total protein in pigeon pea (Singh & Jambunathan, 1982). Globulins are soluble in salt-water solutions and represent approximately 70% of total protein in pulses; albumins are soluble in water and account for 10-20% of the total protein in pulses; glutelins are soluble in dilute acid and base and account for 10-20% of the total protein in pulse seeds. Globulins found in selected Cucurbitaceae seeds exhibited significant anti-hyperglycemic activity (Teugwa, Boudjeko, Tchinda, Mejiato, & Zofou, 2013). The lysine content in pulse seeds is relatively high compared to cereal crops and grains such as rice. Its domination in the legumes is pivotal in providing the essential amino acids required for proper human nutrition (Duranti, 2006). Protein isolates from plant origin have enormous potential and prospect in the food industry for nutritive and physico- chemical properties and being cost effective. Nutritional and functional analysis of the protein isolates obtained using different extraction techniques had promising results for their superior quality possible use in food products (Adenekan, Fadimu, Odunmbaku, & Oke, 2018). The solubility of protein and its functionalities are affected by extraction conditions, solvent type and heat treatment (Liu, 1997).

The bioactive properties of proteins and peptides sourced from pulse seeds have gained increased interest in food science and nutrition fields for their potential benefits in treating and reducing the onset of disease (Campos-Vega, Oomah, Loarca-Piña, & Vergara-Castañeda, 2010). Bioactivity essentially refers to an altering effect on any specific biological progression in a living cell or organism and is frequently used about human health. Bioactive components are not just limited to the drugs but are also vital regarding food components with health benefits. Food and Drug Administration (FDA) approved a health claim for soy protein and its role in reducing levels of LDL and HDL/total cholesterol and thus the risk of coronary heart disease (FDA, 1999). Research on Pigeon Pea protein, derived from leaves, suggests that its protein show both preventive and therapeutic activity against chloroform-induced hepatotoxicity, attributed to its anti-oxidative defense mechanism (Ghosh, Sarkar, & Sil, 2006). Very few publications have studied the bioactive proteins in Pigeon pea seeds. On the other hand, extensive studies have engrossed to the other pulse proteins and their health benefits. Most of the studies focused on the nutritive or functional properties of Pigeon pea proteins and compared their properties with proteins from other pulse crops such as soybean.

Since the bioactivity of protein is dependent on its structure, the biological effect has a likelihood of modification after the extraction procedure. Understanding the properties of proteins in Pigeon pea and its related health benefits will fill the gap in research on Pigeon pea study.

Carbohydrates (Non-starch polysaccharides and starch) in Pigeon pea

Carbohydrates account for 55% to 65% dry matter in pigeon pea (Bravo, Siddhuraju, & Saura-Calixto, 1999) including starch and non-starch polysaccharides. Due to poor digestibility compared to cereal starch, legume starches promote slow and moderate postprandial glucose and insulin responses and have low glycemic index due to higher amylose content than cereals (Sajilata, Singhal, & Kulkarni, 2006). Legumes contain a large amount of starch and fibers that are resistant to digestion in the small intestine and pass into large intestine for bacteria fermentation producing short-chain fatty acids (Chung, Shin, & Lim, 2008). Resistant starch is a portion of total starch which is not hydrolyzed in the small intestine and is thought to be a healthy dietary fiber (Higdon, 2007). Non-starch polysaccharides in pulses are reported with various health benefits including gut health, colon cancer prevention, anticancer and anti-inflammation effects, etc. The non-starch polysaccharide is a major portion of the dietary fiber in pulses. Pigeon pea is a good source of dietary fiber (Table 1), its incorporation into food products as functional food can enhance human health and its potential use as a novel ingredient in the food industry can modify and enhance the texture of food products.

Some studies investigated starch properties in Pigeon pea. Sandhu and Lim (2008) investigated *in vitro* digestibility of Pigeon pea starch, and their results confirmed that Pigeon pea starch was highly resistant to digestion. In their study, Pigeon pea starch had the highest values for amylopectin (molecular weight 389×10^6 g/mol) and amylose (molecular weight (3.64×10^6 g/mol). Several properties of legumes affect starch digestibility, including a high content of viscous soluble dietary fiber constituents, the presence of various antinutrients, polyphenols, phytic acids and relatively high amylose/amylopectin ratios (Tharanathan & Mahadevamma, 2003; Zhou, Hoover, & Liu, 2004). There is no recent data available on non-starch polysaccharide in Pigeon pea. Few earlier studies on polysaccharides of different pigeon pea cultivars were conducted concerning dehulling and milling properties of the seeds. Water-soluble (WS-NSP), water-insoluble (WIS-NSP), and a cellulosic fraction of whole grain were isolated and evaluated for uronic acid content, hexoses, and pentoses. Total non-starch polysaccharides ranged between 18.72 and 19.84% and cellulosic content ranged from 8.37 to 9.56% (Ramakrishnaiah & Kurien, 1985). Swamy et al. (1991) published his work on the nature of carbohydrates discovered in different pigeon pea cultivars. They concluded that cultivars which are easy to mill predominately have gummy arabinogalactan and hygroscopic polysaccharides on the other hand higher pectin content is found in difficult to mill ones. They also reported the occurrence of glucuronic and galacturonic acid along with arabinose and xylose in the hull and only galacturonic acid in the cotyledons.

Further studies can explore the detailed information of non-starch polysaccharides in Pigeon pea, including monosaccharide composition, molecular weight, functional and rheological properties. The effect of total polysaccharide concentration on protein and starch digestibility can also be explored.

Minor bioactive components in Pigeon pea

Other than the major components such as protein and carbohydrates, there are minor components consisted in Pigeon pea exhibiting bioactive effects. There is little information available yet regarding the phytochemical profiling of small molecules in Pigeon pea seeds. Phytochemicals are the chemicals which are produced by plants through primary or secondary metabolism. Campos-Vega, Loarca-Piña, and Oomah (2010) summarized the minor components of pulses including phenolic compounds, enzyme inhibitors, and lectins, fatty acids, phytosterols, phytic acid, and saponins. In current studies, most of the so-called antinutrients (such as tannins, saponins, and phytic acids) have been found with health-promoting properties if used properly (Bawadi, Bansode, Bansode, Truax, & Losso, 2005). Some of the bioactive substances are sensitive to processing conditions, for example, enzyme inhibitors and lectins have little effect after cooking (Campos-Vega, Loarca-Piña, & Oomah, 2010). After studying minor bioactive components in soybean and common bean, Xu and Chang (2011) indicated that different processing methods might have various effects on phytochemical profiles and bioactivities. Among many of the bioactive substances in pulses, the most extensively investigated compounds include phenolic compounds, phytic acid and saponins (Xu & Chang, 2011); (Marathe, Rajalakshmi, Jamdar, & Sharma, 2011); Campos-Vega, Loarca-Piña, & Oomah (2010).

Phenolic compounds

Phenolic compounds are one of the most broadly occurring groups of phytochemicals as they not only have biological activity in plants but also play an important role in plant's growth and defense mechanism against competitors like pathogens and predators (Molyneux, Stephen T. Lee).

Major phenolic compounds in pulses consist mainly of phenolic acids, flavonoids, and tannins (Campos-Vega, Loarca-Piña, & Oomah 2010). Phenolic complexes are one of the main contributors to the antioxidant activities in plants. Antioxidants protect the body against the damaging effects of free radicals by neutralizing them via donating one of their electrons (Fang, Yang, & Wu, 2002). Chemically phenolic compounds(polyphenols) have one or more hydroxyl groups attached to aromatic hydrocarbons, and a can range from simple to highly polymerized compounds (Bravo, 1998). Phenolic acids exhibit antioxidant activity depending on the numbers and positions of the hydroxyl groups relative to the carboxyl functional group (Rice-Evans, Miller, Paganga, 1996; Robards, Prenzler, Tucker, Swatsitang, & Glover, 1999). (Figure 1).

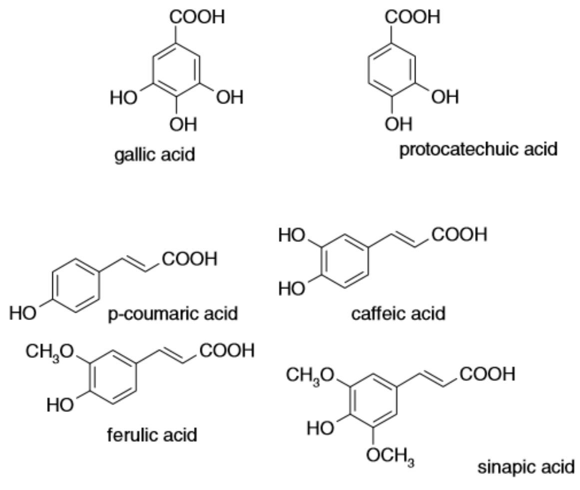

Figure 1. Examples of phenolic (hydroxybenzoic and hydroxycinnamic) acids: (Balasundram, Sundram, & Samman, 2006)

Free radicals are a byproduct of biological reactions and are responsible for several diseases such as cancer diabetes and degenerative ailments in the body (Sarma, Mallick, & Ghosh, 2010). Pulses contain a varied amount of total phenolic compounds and possess a varied range of antioxidant activities. Among the thirty different varieties of commonly consumed legumes in India, Pigeon pea showed intermediate antioxidant activity evaluated using DPPH, ABTS and FRAP assays. The antioxidant activity correlated with total phenolic content ((Xu & Chang, 2011); (Marathe, Rajalakshmi, Jamdar, & Sharma, 2011). A recent study by Maneechai, Rinthong, Pumyen, Koonkratok, and Sripirom, (2013) gave the total phenolic content of pigeon pea root, stem, leaf, and seed in ethanol, dichloromethane and water extracts as 0.870 – 4.408, 0.222 – 2.833 and 0.778 – 3.972 mg/ GAE/ mg respectively. Kamath, Arunkumar, Avinash and Samshuddin (2015) estimated the total phenolic content of whole pigeon pea seeds in 80% aqueous acetone solvent 0.65 ± 0.03mgGAE/mg. The total phenolic content of methanolic extract of whole pigeon pea seeds was reported 9.44 ±0.02 mg GAE/g and total flavonoid content as 8.65 ± 0.61 mg CAE/g (Rani, Poswal, Yadav, & Deen, 2014). In literature, phenolic and flavonoid content of pigeon pea has varying values as extraction of phenolic compounds depend on several factors such as solvent, temperature, and time of extraction (Al-Saeedi & Hossain, 2015). Macerated powdered pigeon pea seeds in methanol exhibited varied, 35.50-153 mg of GAE/g, total phenolic content and 0.16-1.58 mg of QE/g of total flavonoids in different solvent fractions (Al-Saeedi & Hossain, 2015).

Flavonoids and Tannins

The pigments that impart color to the most flowers, fruits, and seeds are flavonoids. New studies emphasize the importance of flavonoid-rich food in our diets as they protect against diseases related to free radicals. Flavonoids make up the largest plant phenolics that are a group of plant's secondary metabolites with several metabolic functions. They are low molecular weight compounds, structurally containing fifteen carbon atoms, comprising of two benzene rings arranged in a C6–C3–C6 conformation linked via heterocyclic pyran ring. (Figure 2).

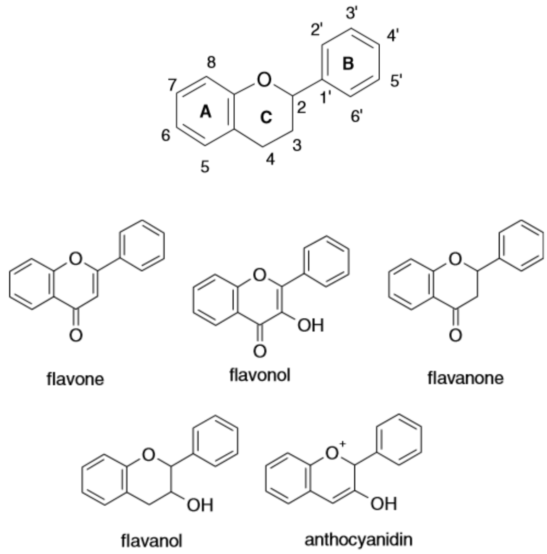

Figure 2. Generic structure and some of the major classes of flavonoids. (Balasundram, Sundram, & Samman, 2006)

Position, substitution, and extent of hydroxyl groups in flavonoids are responsible for the considerable antioxidant, chelating, and radical scavenging activity (Heim, Tagliaferro, & Dennis, 2002). Flavonoids and tannins are regarded as the key dietary phenolic compounds (King & Young, 1999). Tannins are comparatively high molecular weight compounds and can be subdivided into hydrolyzable and condensed tannins (Porter, 1989). Condensed tannins are secondary metabolites of flavonoids with diverse metabolic and physiological roles in plants including protection against the damaging effects of insects and microorganisms (Wilska-Jeszka, 2007). Tannins are fairly abundant in most legumes and found mostly in colored hulls of seeds. Antioxidants in the darker seed coats have the scope of in-depth study because they are thought to contain anthocyanins and other secondary metabolites. Major subgroups of secondary metabolites are chalcones, flavones, flavandiols, flavonols (Catechins), proanthocyanidins (condensed tannin), and anthocyanins (Ferreyra, Rius, & Casati, 2012) Fig 2. Reddy, Pierson, Sathe, and Salunkhe (1985) estimated the condensed tannins in commonly consumed dry beans with pigeon pea ranging between 3.30-17.10mg/g, higher than cowpea and chickpea and comparable to kidney bean and black gram. Ene- Obong (1995) estimated 0.14-0.97 mg/g of tannins in pigeon pea seeds. Recently Nix, Paull, and Colgrave (2015) profiled total 27 flavonoids in whole pigeon pea plant containing six flavones, eight isoflavones, four flavonols, two anthocyanins, three flavanones, three isoflavones and a single chalcone. Soaked, sliced, and incubated under non-sterile conditions pigeon pea seeds tested positive for the phytoalexins cajanol, cajanin and two unidentified isoprenylated flavones (Dahiya, Strange, Bilyard, Cooksey, & Garratt, 1984). Studies have shown these phytochemicals exhibit antimicrobial, anti-oxidative, and antifungal properties (Kodera et al., 1989). Growing scientific work on the biological activities of flavonoids has amplified its interest in the probable applications of these compounds in medicine and agricultural sciences. Cajaninstilbene acid (CSA), pinostrobin, vitexin and orientin extracted from Pigeon pea leaves displayed pharmacological and antioxidant activity (Wu et al., 2009). In a study pigeon pea extract in ethanol was analyzed by LC-MS/MS and a potent antioxidant compound, apigenin, was discovered (Gao et al., 2012). Pigeon pea contains vitexin and isovitexin; two flavone C-glucosides identified to possess antimicrobial effects (Nix, Paull, and Colgrave, 2015). The occurrence of flavanones, naringenin, and its effectiveness to inhibit the growth of *S. thypi, S. aureus*, and *E. coli* confirms the traditional use of the plant in the treatment of typhoid disease (Agus, Achmadi, & Mubarik, 2017).

All processing steps result in significant decrease in total phenolic content which can be attributed to the synergistic combinations or counteracting of several factors including oxidative reaction, leakage of water-soluble antioxidant compositions, formation or breakdown of antioxidant composition, and solid loss during processing (Campos-Vega, Oomah, Loarca-Piña, & Vergara-Castañeda, 2010).

Phytic acid

Major phosphorus storage form in pulses is in the form of phytic acid located in the protein bodies in the endosperm. Phytic acid, myo-inositol hexakisphosphate (IP6), occurs in many seed plants usually in the form of soluble sodium or potassium salts, known as phytates (Morris & Hill, 1996; Kumar, Sinha, Makkar, & Becker, 2010). The chemical structure has six groups of phosphates attached to the inositol ring. Fig 3

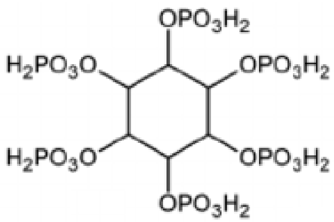

Figure 3. The generic structure of phytic acid. (Anson, Hemery, Bast, & Haenen, 2012)

Phytic acid prevents kidney stones, delay postprandial glucose absorption, reduce the bio-accessibility of toxic heavy metals, and have antioxidant activity by chelating iron and copper (Minihane & Rimbach, 2002; Jenab & Thompson, 2002; Grases et al., 2006). High fiber foods with phytic acid have shielding effects against cancer and heart disease (Fredlund, Isaksson, Rossander-Hulthén, Almgren, & Sandberg, 2006). The dietary phytic acid may help in lowering the occurrence of colonic cancer and defend against other inflammatory bowel diseases (Graf & Eaton, 1990; Vucenik & Shamsuddin, 2006). Phytic acid contributes 66-75% of phosphorous in pigeon pea (Ene-Obong, 1995). Chitra, Vimala, Singh, and Geervani (1995) carried out studies on phytic acid in numerous genotypes of soybean, urad bean, mung bean, pigeon pea, and chickpea. Results indicated that pigeon pea has intermediate value of phytic acid (12.7 mg/g), soybean being the richest source of phytic acid (36.4 mg/g), followed by urad bean (13.7 mg/g), mung bean (12.0 mg/g) and chickpea (9.6 mg/g). Eugene R. Morris and A. Morris & Hill (1996) estimated 40% higher phytic acid content in pigeon (10mmol/kg) phytates than in chickpeas (6mmol/kg). Cooking may decrease the total phytic acids content (Chen, 2004; Phillippy, Lin, & Rasco, 2004). Duhan, Khetarpaul, and Bishnoi (2002) observed almost half fold decrease in phytic acid content in cooked pigeon pea than the raw seeds.

Saponins

Saponins are low molecular weight plant glycosides, reported in many edible legumes and little is known about detailed structures. Chemically, saponins have a part of carbohydrate attached to a triterpenoid or steroids, known as sapogenins (Figure 4).

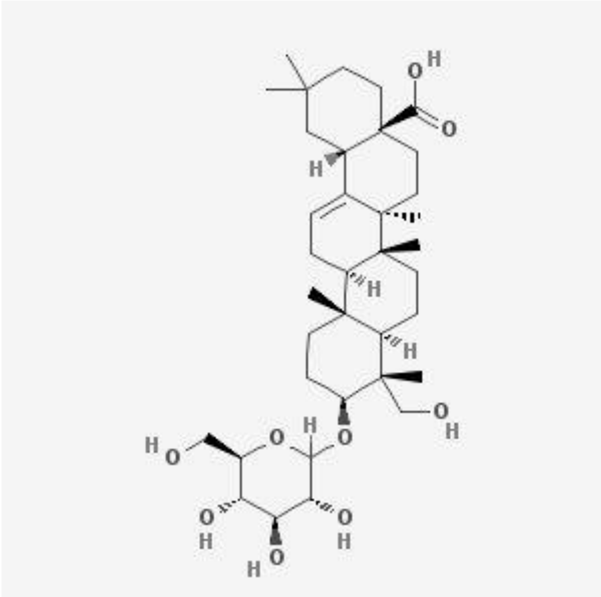

Figure 4. Structure of a saponin molecule. Retrieved June 29, 2017, PubChem Compound Database.

Evaluation of soybean seeds indicates that there are five non-polar sapogenins which can bind monosaccharides like galactose, arabinose, rhamnose, glucose, xylose and glucuronic acid (Krishnamurthy, Tsukamoto, Yang, Lee, & Chung, 2012). Like detergents, they form a foam when mixed with water and can bind with water and fats or oils. Saponins have also been reported to have anti-hyper cholesterol, anti-inflammatory, cardiac depressant properties (Harborne, 1984), possess anti-cancer activity, and lower blood glucose response (Shi et al., 2004). Chu et al. (2013) indicated positive effects of saponins on myocardial health.

Saponin content varies greatly among different pulses. Duhan, Khetarpaul, and Bishnoi (2001) reported that saponin contents in Pigeon pea varied from 2164 to 3494mg/100g in different cultivars. Processing and cooking methods resulted in a reduction of saponin in all the pigeon pea cultivars.

Key physiological activities of Pigeon Pea seeds

Pigeon pea is an important economic crop for both human and animal nutrition and its seeds are a major protein source. Significant literature studies point out the research work on its leaves, stems, and roots for bioactive and physiological aspects, mainly because of the ample availability of these non-consumable parts of the plant. In addition to an important component of food due to its high protein content, the seeds have been part of traditional and folk medicine for the treatment of inflammation, measles, blood disorders, energy stimulant, and as a diuretic (Pal, Mishra, Sachan, & Ghosh, 2011; Duke, 1981). Recent work by Mathew, Lydia, Manila, Divyasree, & Sandhya (2017) identified the broad range of phytochemicals ligands with candidate disease proteins using GC-MS, in all parts of pigeon pea. This study specifically revealed the compounds from pigeon pea seeds that can be potential drug candidates.

Table 2: Key physiological activities of Pigeon Pea seeds

Physiological Activity	Experimental Method	Results	Reference
Antihyperglycemic & Lipid peroxidation	Antioxidant activity of an extract of germinated pigeon pea (Cajanus cajan) in alloxan-induced diabetic rats. Dinitrosalicylic acid (DNSA) and in vitro starch iodine method for the measurement of Inhibition of α-amylase and α-glucosidase and investigation of blood glucose levels of the animal.	The indirect effect of total phenolics with increased antioxidant activity leading to the inhibitory potential of carbohydrate digesting enzymes and a positive correlation between consumption of germinated pigeon pea and controlling hyperglycemia. Reduction in lipid peroxidation and reduced fasting blood glucose level in diabetic rats.	(Uchegbu & Ishiwu, 2016)
Antioxidant potential of biological pigeon pea proteins from seeds.	The potential antioxidant activity of both enzymatic antioxidant-like activity and anti-oxidative cellular damage in TK6 human lymphoblasts. The protective effect measured by employing mitochondrial dehydrogenase (MDH), and lactate dehydrogenase (LDH) activity assays and the anti-oxidative DNA damage was assessed using comet assay.	Proteins isolated from pigeon pea seeds possed anti-oxidative effects on H_2O_2-induced cellular damage.	(Muangman, Leelamanit, & Klungsupaya, 2011)
Anti-oxidant potentials and anti-hyperglycemic activity	The crude methanol extract was evaluated for its antihyperglycaemic activity in starch-induced postprandial hyperglycemic rats.	Methanolic extracts of seed husks were found to be the rich source of polyphenols and protein and possessed potent free radicals scavenging, anti oxidant activities in vitro. Mitigated starch-induced postprandial glycaemic excursions and reduced glycaemic load in rats similar to the standard drug acarbose.	Ashok et al. (2013)
Anti-hyperglycemic activity	Single doses of unroasted seeds (60% and 80%) and administration to normal as well as alloxanized mice.	Significant reduction in the serum glucose levels after 1-2 hours and a significant rise at 3 hours.	(Amalraj & Ignacimuthu, 1998)
Anti-hyperlipidemia activity	Effect of the globulin fraction from red gram (Cajanus cajan) in rats fed with a high-fat, high cholesterol diet.	Total and free cholesterol, triglycerides in the serum, liver, and aorta of rats receiving the globulin fraction were much lower than in the high fat, high-cholesterol fed controls.	(Prema, & Kurup, 1973)
Anti-hyperglycemic activity	Pigeon pea was cooked and tested for blood glucose response among healthy human volunteers.	Cooked pigeon pea indicated substantial lower blood glucose	(Panlasigui, Panlilio, & Madrid, 1995)

		response compared to bread among the group of healthy volunteers.	
Anti-dyslipidemic activity	The antidyslipidemic activity of pigeon pea was evaluated by high-fat diet (HFD) hamsters model, in which the level of high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein-cholesterol (LDL-C), total cholesterol (TC), and total triglyceride (TG) were examined.	Statistical results showed pigeon pea significantly elevated hepatic carnitine palmitoyltransferase-1 (CPT-1), LDL receptor, and cholesterol 7α-hydroxylase (also known as cytochrome P450 7A1, CYP7A1) expression to attenuate dyslipidemia in HFD-fed hamsters and markedly increased antioxidant enzymes in the liver of HFD-induced hamsters.	(Dai, Hsu, Huang, Wu, 2013)
Antisickling activity	Antisickling experiments based on the estimation of free phenylalanine in the methanol (water-soluble) extract of the white variety seeds.	The presence of phenylalanine amino acid alone could account for about 70% of the antisickling potency of Cajanus cajan seed extract.	(Ekeke & Shode, 1990)
Anti-inflammatory activity	Cajaninstilbene acid (CSA) and its derivatives effect on cytokines (TNF-α and IL-6) production in RAW264.7 cells (mouse leukemia virus-induced tumor macrophage). Cytokines were estimated using an enzyme-linked immunosorbent assay (ELISA). Anti-inflammatory mechanism of this type of compounds was measured by western blot and reverse transcription-polymerase chain reaction (RT-PCR).	Cajaninstilbene acid (CSA) only found in pigeon pea and extracted from its leaves along with its synthesized derivatives revealed strong inhibition activity on the release of nitric oxide(NO) and inflammatory factor TNF-α and IL-6 in lipopolysaccharides (LPS)-stimulated mice macrophages.	(Huang, et al. 2016)
Anti-inflammatory activity	Investigational study on the effect of 50% ethanol extracts of pigeon pea, as well as its major component, cyanidin-3-monoglucoside, an anthocyanin, on DNA damage, the activity of antioxidant enzymes, and free radical scavenging capacity in hydrogen peroxide (H_2O_2)-treated RAW264.7 macrophages.	50% ethanol extracts of pigeon pea and cyanidin-3-monoglucoside suppressed the production of inflammatory cytokines, including TNF-α, IL-1β, and IL-6, in these macrophages.	(Lai, Hsu, Huang, & Wu, 2012)
Anti-inflammatory activity	The anti-inflammatory activity of hexane extract 200 and 400 mg/kg was evaluated using the carrageenan-induced rat paw edema at 1, 2, and three hours. ELISA detected the serum tumor necrosis factor-α, interleukin-6, and immunoglobulin G levels. The DPPH radical scavenging, total reduction capability, and inhibition of lipid peroxidation of butanol fraction were evaluated.	The hexane extract of C. cajan seeds inhibited the inflammation induced by carrageenan and displayed the capacity to decrease TNF-α and IL-6 in the serum of rats with carrageenan-induced inflammation	(Hassan, Matloub, Aboutabl, Ibrahim, & Mohamed, 2016)
Anti-hypertensive activity	Investigation of the production of nattokinase, a serine fibrinolytic enzyme, in pigeon pea by Bacillus subtilis fermentation to produce nattokinase in an animal model.	Water extracts of pigeon pea (100 mg/kg body weight) and water extracts of B. subtilis-fermented pigeon pea (100 mg/kg body weight) significantly improved systolic blood pressure (21 mmHg) and diastolic blood pressure (30 mmHg) in spontaneously hypertensive rats.	(Lee, Lai, Wu, 2015)

Application of Pigeon pea in foods

Pigeon pea is an excellent source of protein which makes it the perfect supplement to traditional cereal. Incorporating legume flours as food ingredients are dependent on the functional and sensory characteristics responsible for an acceptable end product. The functional properties include emulsification, foaming, gelation, texture, viscosity, water and oil absorption capacities (Adebowale & Lawal, 2004.)

Table 3: Application of Pigeon pea in foods

Food category	Application	Results	Reference
Pasta	The fermented pigeon pea flour was used as an ingredient to make pasta products in a proportion of 5, 10, and 12%.	The enhanced pasta had longer cooking times, higher cooking water absorptions, higher cooking loss, and higher protein loss in water than control pasta (100% semolina). Fortified pasta with 5 and 10% fermented pigeon pea flour had an acceptability score similar to control pasta. Pasta supplemented with 10% fermented pigeon pea flour had higher levels of protein, fat, dietary fiber, mineral, vitamin E, and antioxidant capacity than 100% semolina pasta.	Torres, Frias, Granito, and Vidal-Valverde (2007)
	Fermented and germinated Pigeon pea flours into semolina pasta	Fermentation and germination of pigeon pea seeds improved some essential amino acids. Supplementation in semolina pasta can improve protein quality.	Martinez-Villaluenga, Torresb, Friasa, & Vidal-Valverde (2010)
Noodles	Physicochemical and pasting properties of pigeon pea and rice starches were studied to evaluate their suitability for noodle making.	Noodles prepared from70 g pigeon pea, and 30 g rice starch/100 g of total starch scored the highest for overall acceptability.	(Yadav, Yadav, Kumar, 2011).
Biscuits	Addition of up to 25% Pigeon pea flour into cereal biscuits. Quality assessment of the blends for their potential use in the preparation of complementary foods and as substitute raw materials for wheat in the production of pasta, puddings, and biscuits. Biscuits baked from millet flour and pigeon pea flour blends in ratios of 25%, 35%, and 50%. Nutritional and sensory assessment for final products.	Biscuit with 25% supplementation had a low sensory evaluation score. Level of protein and fiber increased. Biscuits with a more modest 15% supplementation of pigeon pea flour demonstrated satisfactory results on both nutritional and sensory quality. They all contained high proportions of protein, fat, and digestible carbohydrate. All the biscuits had high sensory ratings. The recipe with the 65% millet and 35% Pigeon pea flour blend resulted in the highest scores for flavor, texture and general acceptability	Tiwari, Brennan, Jaganmohan, Surabib, and Alagusundaramb (2011). Eneche, 1999.
Flour properties	Quality properties of flour blends of unripe cooking banana, pigeon pea, and sweet potato.	The crude protein, fiber, ash, foaming, emulsion, and least gelation capacity of the blends increased as the pigeon pea flour level increased. Cooking banana, pigeon pea, and sweet potato flour blends are good sources of protein, fiber, and carotenoids.	Ohizua, et al. (2017)
	Simplex centroid mixture design was used to evaluate the chemical, functional and sensory properties of flour blends of water yam, pigeon pea, and carrot pomace.	The addition of pigeon pea and carrot pomace improved some macro- and micro-nutrient composition of water yam flour. Flour blends have the potential for the preparation of various specific food items.	Adeola, et al. 2017
	Functional properties of raw and processed pigeon pea flour were investigated and compared with raw soy flour.	Processing helped in increasing the fat absorption capacity of pigeon pea flour than raw soy flour	Okpala, & Mamah, 2001
Baked snacks	The flour of pigeon pea incorporated in backed snacks with extruded cassava and sorghum flours.	Increasing nutritional quality with acceptable sensory ratings	Rampersad, Badrie, & Comissiong, 2003; Mbaeyi-Nwaoha and Onweluzo, 2013.
Natto pigeon pea	Preparation of natto-pigeon pea with immobilized *Bacillus* natto and compared with the preparation of natto-soybean.	The fibrinolytic activity of natto-pigeon pea was higher than that of natto-soybean. Higher sensory scores than that of natto-soybean on flintiness, brightness, flavor, solubleness, chewiness, and off-odor, and no obvious differences in overall color homogeneity, stringiness, adhesiveness, and color intensity.	Feng, et al., 2015

Interactions

In a real food system, bioactive components may interact with other components thus affect absorption, metabolism, bio-accessibility, and bio-accessibility of the individual phytochemicals (Tiziani, Schwartz, & Vodovotz, 2008). The effect of processing on individual components within a food system and the possible interactions among different components have not been fully understood.

It is reported that protein may interact with phenolic compounds thus affect its bio-accessibility, while carotenoids in the same system were not affected (Rawel, Czajka, Rohn, & Kroll, 2002). It is unknown yet after incorporating Pigeon pea into a cereal diet, how the minor substances will interact within the food matrix and impact their bio-accessibility and bioactivity in the intestinal tract.

Summary

Pigeon pea is a perennial tropical crop primarily grown in Asia and Africa, and its seeds are consumed as a rich source of protein and carbohydrates both in fresh and dried forms. This crop has been successfully grown in some southeastern states but still considered as a novel pulse here in the US. Majority of the work focused on its non-consumable parts like leaves, stems, and roots. Literature studies indicate that pigeon pea has the potential to prevent and treat many human diseases such as bronchitis, pneumonia, measles, hepatitis, yellow fever, ulcers, diabetes, and certain forms of cancer.

Along with protein and fiber, it has a decent number of health-promoting phytochemicals. Important phytochemicals found in pigeon pea seeds are phenolic acids, flavonoids, tannins, saponins, and phytic acid. These minor components predominately exhibit and are capable of antioxidant, antidiabetic, and anti-inflammatory activities. Some studies describe the bioactive role of protein fractions, especially as an antihyperglycemic factor. Seeds are the edible and non-perishable part of this crop with the feasibility of addition in food products. Exploring the non-starch polysaccharide fractions and functional properties of the pigeon pea flour can make it a gluten-free substitute for cereals. Pigeon pea seeds being a rich source of protein, fiber, phytochemicals, and global sensory acceptability have a potential to be incorporated as a functional food that may provide benefits beyond basic nutrition.

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