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Processing of Pulses: a Platform for Innovation

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Abstract

The triple burden of nutrition poses a serious challenge to the long-term sustainability of the growth story of emerging countries like India. Food businesses, situated at the intersection of agriculture, health and industrial economic systems, can contribute importantly to solving this problem by making nutritional security a cornerstone of their strategy as populations move from subsistence to industrialized modern markets. This shift also corresponds with a shift for innovation strategies and pipelines to optimize economic and human development. We call this convergent innovation. Pulses, a naturally nutritious agricultural commodity high in proteins, dietary fibers, minerals, and phytonutrients, are well positioned as a food-based convergent innovation solution to the triple burden of malnutrition. This paper discusses how modern processing techniques, such as roasting, can be used to create foods that better meet consumer demands through new nutrient, sensory, and behavioral profiles, while also contributing to collective health and economic systems across the agri-food value chain.

1.0 Introduction

Pulses are nature's gift to mankind and are appropriately referred to as the smart food of the future. They are a fantastic source of proteins, dietary fibers, minerals, and phytonutrients. When consumed, particularly with cereals and millets, the quality of the protein found within pulses, and the digestibility of this protein significantly improves. Pulses have been consumed by human beings and animals for many centuries and have proven to be an excellent source of vegetarian protein. They have low glycemic indexes, they are free of cholesterol and gluten, and they are not a common source of food allergens.

Pulse flours possess many of the functional properties similar to egg and dairy proteins; such flours have the potential to be used in many food preparations including confectionery and baked goods. Meta-analyses of various clinical studies have demonstrated the potential health benefits of daily consumption of pulses in preventing lifestyle diseases like diabetes, cardiovascular diseases, and cancer. They also possess a low water-footprint, low carbon-footprint, and pulse crops are efficient in enriching soils with nitrogen and thus significantly reducing the need for fertilizers.
Nonetheless, pulses can be slow to cook, difficult to digest and contain some undesirable antinutrients. Traditional uses of pulses in many countries have taken these limiting factors into consideration and developed several processing conditions largely used in home cooking that help improve taste, aroma, digestibility, protein bioavailability and reduce antinutrients, enabling their daily consumption. Traditional processing conditions include dehusking, splitting, soaking, germinating, drying/roasting, fermentation, and so on.

Processing conditions can alter the chemistry, physical properties, and nutritional value of pulses significantly. Understanding these changes are necessary to produce products that capitalize on aroma and taste, as well as optimize the nutritional value of pulses and pulse based ingredients such as bread, soups, noodles, pasta, cookies, and confectionaries. Such an understanding will also enable the development of processing conditions that can be scaled up for commercial production.

Since pulses are the most cost-effective and sustainable protein source in the world, they are in a unique position to meet the dietary needs of a growing human population. As the world's population is projected to reach 9.7 billion people by 2050, it is imperative that we capitalize on the cultivation, processing, product development, distribution, and marketing, of this remarkable crop. Pulse product innovation, therefore, can advance pulses as the food crop of the future driving food security and transforming the agri-food industry through innovative and sustainable practices. However, the transformative potential of the humble pulse has been largely untapped. Despite their versatility, affordability, and nutritional profile, pulse consumption is declining in India, one of the largest consumers of pulses. It is imperative now, more than ever before, to develop innovative and sophisticated processing, product development, and marketing techniques to produce commercially-ready pulse ingredients for both the Indian and Canadian food sectors, as well as the global market.

This paper will guide the food sector in identifying processing/milling strategies to achieve pulse flour/protein specifications with the required functionality and nutritional profiles needed for a wide range of food applications (as functional food ingredients and protein alternatives).

2.0 The Importance of Pulses

Pulses are the dry, edible part of non-oil legumes of the Fabaceae family. They grow in distinct pods of different size, shape and colour. Legumes which are cultivated and harvested for their dried seed are the ones which are classified as pulses[1]. There are 11 types of pulses acknowledged by the Food and Agriculture Organisation (FAO) of the United Nations. These include dry beans, broad dry beans, dry peas, chickpeas, dry cowpeas, pigeon peas, lentils, Bambara beans, vetches, lupins and minor pulses (guar, velvet, yam beans etc.)[2]. More than 100 varieties of pulses are grown all around the world with China, India and Canada being at the top of total pulse production.

3.0 Nutritional Value of Pulses

Pulses provide a large variety of nutrients depending on the type of pulse. The primary nutrient which is ubiquitous to almost all the pulses is digestible protein[3][4]. Pulses are rich in essential amino acids such as lysine and threonine which are not so common in other plant proteins. While on the downside, pulses have very low content of certain other amino acids such as methionine, tryptophan, and cysteine making them not a complete protein source[5] but when combined with other protein sources, such as cereals, pulses can prove to be a very rich plant-based protein source and the problem of protein-calorie malnutrition, which is a major problem in most of the developing countries, can be solved significantly[6][7]. Pulses combined with cereals is a great combination which provides good quality of protein and all essential amino acids in proper proportions[8]. Pulses have a very low glycemic index ranging between 29 to 48 indicating that the carbohydrate present could be in the form of slow digesting sugars such as resistant starch which doesn't have much impact on blood glucose levels[9][10]. Also, pulses have a very low-fat content which is about 0.8-1.5% of the pulse grain weight which is markedly low when compared with other seeds and grains. In addition, fats found in pulses are mainly mono- and poly-unsaturated fats which are considered to be beneficial for human metabolic functions[11].

Besides the above-mentioned macro-nutrients, pulses also provide a large variety of micro-nutrients such as selenium, thiamin, niacin, folate, riboflavin, pyridoxine, potassium, zinc, vitamin E, copper and vitamin A which all have an essential role in proper functioning of the body and their composition depends largely on the type of pulse being consumed[12][13]. Nowadays legume-based flours are gaining popularity as ingredients in ready-to-eat or ready-to-prepare snacks[14]. Details on the various nutrients in pulses are given in Table 1.

Table 1. Nutritional value of some pulses [15]

Country, Region	Common name	Species	Energy (kcal)	Carbohydrates (gm)	Fibers (gm)	Proteins (gm)	Fats (gm)	Calcium (mg)	Iron (mg)	Phosphorus (mg)
Canada	Black turtle bean	Phaseolus vulgaris L	297	37.8	21.6	21.5	1.9	112	7	491
Canada	Yellow pea	Pisum sativum L	306	45.3	19.6	17.9	1.5	60	5.3	272
Canada	Chickpea	Cicer arietinum	339	42.4	17.1	21.2	5.6	148	8.4	307
India	Cowpea	Vigna unguiculata (L) Walp.	333	51	11.4	21	2.5	125	5.8	213
India	Mung bean	Vigna radiata (L) R Wilczek	321	48.7	17.1	20.2	1.3	93	4.1	310
India	Mungo bean	Vigna mungo (L) Hepper	314	41.7	20.1	23.6	1.3	117	7.1	304
India	Lentil	Lens culinaris Medik	319	45.1	16.6	24.1	1	75	7.5	271
India	Pigeon pea	Cajanus cajan (L) Huth	306	39.6	22.5	22.4	1.5	137	5.3	308

4.0 Processing of Pulses: A Focus on Roasting

It is essential to cook pulses before consumption to enhance digestibility, taste, texture, availability of nutrients, anti-oxidant activity and to reduce anti-nutrient activity and microbial loads. For this, a variety of cooking methods can be employed like boiling, grilling, roasting, steaming, etc. The type of cooking depends on the type of food material and its thermos-sensitivity. The traditional processing of pulses is usually done in two stages. In the first stage, dehulling of the whole seeds is done, reducing the anti-nutrients. This stage is followed by either soaking, autoclaving, germination, roasting and fermentation of the dehulled grain [29].

In roasting, heat is transferred into the food from hot surfaces or from the air in a furnace or oven. Simultaneously, the moisture is transferred from the food to air that surrounds it and then is removed from the oven by moving air. In a furnace/oven, the food material gets heated by a varying combination of conduction, convection, and radiation. Depending on the mode of heat transfer, the outcome of the roasting process will vary. Energy consumption during roasting is of the order of 450–650 kJ per kilogram of food. This energy is mainly used to heat the food, removing part of the moisture, formation of an outer crust, browning and caramelization reactions.
Roasting is typically a dry heat treatment which can be done in several ways. Different methods that are used around the world are oven/microwave roasting, sand roasting, hot salt roasting and infrared roasting. Among these methods, sand roasting is the most prevalent one in Asian as well as African countries.

5.0 Types Of Roasting

Sand roasting

Sand roasting is a batch process where the pulse grains are mixed with pre-heated sand which can also be mixed with some salt to impart a salty flavor (i.e., for roasting of salty snacks). Sand is heated with the help of fire woods or any other source of fuel (such as propane gas) in a metallic vessel. The temperature of the sand is kept around 240℃, and the quantity of the sand needed varies from 4-5 times the volume of grains to be roasted[30]. For even distribution of the heat, the mixture must be continuously stirred. In a span of 3-5 minutes, the texture and color of the roasted legume seeds start changing with the production of a pleasantly characteristic aroma.

Once the grains are ready, they are separated from the sand with the help of sieving. Sand roasted chickpeas and peanuts are famous street snacks in countries like India and Pakistan, etc. Sand roasting of chickpea is an age-old processing method used in South India[31]. Although sand roasting is a rather primitive roasting technique, it is the most prevalent method of roasting even today in many countries. There are disadvantages with sand roasting such as poor temperature control, and there may occur significant sand contamination to the grain[32]. With its disadvantages, sand roasting has not been adopted at the industrial scale. Thus alternative methods of roasting that are scalable need to be developed and their processing parameters require optimization and standardizing.

Roasting can also be useful as a pre-treatment method. Roasting can help in making the dehusking of the grains easier since roasting makes the husk crisp and brittle thus more easily separable[33].

By improving flavor, texture, aroma and other physicochemical properties of the pulses via roasting or other thermal treatments, their consumption around the world can be increased. The flour obtained by milling of roasted pulses can be used in bakery products, snacks, soups, etc. imparting the desirable nutritional attributes of roasted pulses.

Microwave roasting

When compared with sand roasting, microwave roasting can be done in a shorter span of time and with better temperature control. Microwave roasting is a more standardized method of roasting. As microwave energy heats the food items from the inside out, there is no prominent crusting or surface hardening due to excessive surface heat[34]. This is, in fact, a limitation of microwave roasting since there is a poor development of flavor and texture when compared with traditional roasting.

Micronization/Infrared roasting

Micronization is a process in which a substance is exposed to infra-red (IR) radiations of a specific wavelength for a specific period. The wavelength of IR radiations may vary from 1.8-3.4 μm and carry a high amount of energy[35]. When these radiations strike the surface of the food, the high energy transmitted is rapidly dissipated at heat [36-39]. This heating effect of radiation is very useful in modifying properties of food items such as pulses. When pulses are exposed to IR radiations the heat thus generated denatures the proteins resulting in the release of carbohydrate molecules initially entrapped between the protein matrix[40]. Because of this both the proteins and carbohydrates become more accessible to enzymes increasing the overall digestibility[41-43].
The major drawback of using micronization is its low depth penetrability[44]. Thus, for efficient use, this process must be used in conjunction with other heating process like microwave heating.

Continuous spiral roasting

For large-scale roasting of grains, coffee, nuts, and legumes, continuous spiral roasters are employed in the industry. In these roasters, material to be roasted is fed continuously from one side of the rotating machine at a constant flow rate, and as the material passes through the spiral drum, set at an appropriate temperature, it gradually gets roasted. The roasting temperature and resident time of the material can be set according to the degree of roasting required.

5.0 Effects of Roasting on Pulses

The purpose of roasting is to alter the sensory properties of foods, to improve palatability in extending the range of tastes, aromas, and textures in foods produced, along with improving their digestibility without compromising their nutritional value[45]. Roasting also inactivates enzymes and micro-organisms, degrades some anti-nutritional compounds and flatulence factors[46] and lowers the water activity of the food to some extent, thereby helping in preserving the food, thus improving economic value[47][48].

Changes in physical properties

Roasting results in a decrease in the bulk density[50]. As the water imbibed on the grain evaporates into steam, puffing of the grain occur leading to voids generation in the cellular matrix. As a result, expansion of starchy endosperm occurs leading to an increase in surface area of the grain. This may affect the functionality of the grain once processed into a flour. Indeed, when roasted legume flour is incorporated with wheat flour into products like bread, it improves dough handling properties and provides a sought after roasted flavor [49].

Nutritional value

During roasting, the physical state of proteins and fats is altered, and starch is gelatinized and hydrolyzed to dextrins and then reducing sugars. The loss of amino acids and reducing sugars in the Maillard browning reaction causes a small reduction in nutritive value. The concentration of thermo stable amino acids such as arginine, aspartic acid, glutamic acid increases, while the heat labile amino acids like lysine, histidine decrease with roasting[51]. Lysine can be lost to the Maillard reaction, which slightly reduces the protein quality, especially if lysine is one of the limiting amino acids in the food. The extent of the loss is increased by higher temperatures, longer roasting times and greater presence of reducing sugars.

Also, it is important to note that roasting has a significant role in the digestion of proteins[52]. Protease inhibitors, present in pulses, inhibit the digestion of proteins in the human gut. These heat labile protease inhibitors are destroyed by roasting, therefore, increasing protein digestibility[53]. Many pulses are rich in globular proteins which are not accessible because of their confirmation. Roasting results in denaturation of globular proteins making them more accessible to proteases which aid protein digestion[54]. Combining roasting with other methods like drum drying changes the structure of starch granules and helps in enhancing the overall digestibility of the starch present[55].

In certain pulses like mung bean, ionizable iron content also increases due to roasting, as heating results in a change in the protein matrix leading to a change in iron-binding properties[56]. Destruction of phytic acid and inactivation of trypsin inhibitors also results in the improved availability of iron.

Quality of the legumes used for animal feed, like lupin and faba beans can be enhanced by dry roasting for making them more digestible as ruminant animal feed[57], by degrading some of the volatile fatty acids [58], denaturing some of the proteins [59], and reducing the antinutrient content [60-62].

Aroma, color and flavor

Pulses have a particular beany flavor which, to some extent, limits their use in a variety of food systems[63][64]. Various cooking techniques can be considered to improve flavor, and roasting is one of them. Roasting results in the production of aromas which make the food material more acceptable. Heating of the food material results in a reaction between sugars and amino acids known as the Maillard reaction. Due to a localized reduction in moisture content at the product surface and the high heating conditions, caramelization of the sugars also occurs. The fatty acids present get oxidized to ketones, alcohols, esters, aldehydes, and lactones due to this heat treatment leading to the release of pleasant aromas. The main reason for the production of aromas is the reaction between the carbonyl groups of sugar and the nucleophilic amino group of the amino acids in proteins. The rate of reaction increases many folds in an alkaline environment due to the increased nucleophilicity of the amino group. The type of the amino acid determines the resulting flavor profile [64][65]. The range of temperature is very important for this reaction as a higher temperature may lead to pyrolysis leading to the production of acrylamides which are known carcinogenic agents with a bitter taste[66]. The type of aroma depends on the combination of fats, amino acids and sugars present, the temperature and moisture content of the food throughout the heating period and the time of heating.

Texture and Crunch

The composition of food, i.e., moisture content, fats, proteins and structural carbohydrates like cellulose, starch, and pectins, generally determines the texture of the food material. Duration and intensity of the heating process during roasting will also have a significant effect on the texture of the material. Roasting results in the formation of a dry crust on the outer side of the food material. With the heat treatment, the water holding capacity of the proteins present in the food is lost, and the proteins became denatured and contracted, leading to a crisper surface. This change in texture occurs as a result of degradation, partial pyrolysis, and denaturation of the protein [67].

Oil absorption capacity

For food formulations, oil absorption is an important aspect. Binding of fat, especially to the protein and carbohydrates in the food stuff, influences its many properties like texture, fat entrapment, emulsification, palatability, etc. The interaction between non-polar side chains present in the proteins in the food stuff and hydrocarbons chains in oils contribute to the oil absorption capacity of the food. Thermal operations such as roasting enhance oil absorption capacity of the grains or the flours to a certain extent. Heating leads to protein dissociation and exposure of the oil binding sites[68]. Prolonged roasting is not recommended in cases where oil absorption capacity of the food stuff is of prime interest[69].

Water absorption capacity

Protein and carbohydrates are the main functional components associated with water absorption capacity in foods. Hydrophilic side chains (polar and charged groups) present on these are responsible for water absorption[70][71]. After application of thermal processing, gelatinization of starch as well as dissociation of protein results in exposure of polar groups which enhance water absorption capacity. This increased water absorption capacity plays a vital role when pulse flours are incorporated[72] into processed food products[73]. Heat treatment also enhances the gelling and emulsifying activity of roasted pulse flour[74]. Gelling properties play a vital role where these flours are used as thickening agents in soups and other similar preparations.

Anti-nutritional components

Anti-nutritional factors are components that reduce the availability of one or more nutrients in the food or feed. Pulses are highly nutritious, but they also contain some anti-nutritional factors that may cause harmful physiological effects[75]. There are many anti nutritional factors such as phytic acid, tannins, gluten, oxalates, lectins, saponins, isoflavones, cyanogens (pigeon pea) to name a few[76]. Pulses are also rich in phosphorus which forms phosphates with phytic acid, the most widely known anti-nutritional component found in pulses[77]. The phytic phosphates thus formed have a negative impact on the digestibility of pulses by interacting with the proteins present and inhibit their solubility[78] and absorption. Phytic phosphates also inhibit digestive enzymes like amylase[79][80] and trypsin[81] which hampers the rate and degree of digestion in the body. Besides this, phytic phosphates also form complexes with minerals like iron, zinc, and manganese thus reducing the bioavailability of these minerals[82]. Hence, adequate processing of pulses is required to overcome the effect of these anti-nutrients, and it has been shown that roasting can successfully deactivate phytic phosphates. It has been observed that heating pulses by roasting reduce phytic acid content by 25-35%. Indeed, the endogenous phytase activity is greatly reduced due to the heat supply in roasting making the digestion of roasted pulses easier and efficient[29; 83]. Amongst different cooking methods like roasting, pressure cooking and boiling, the most effective method that maximally inhibits trypsin inhibitor activity was found to be roasting[84-86].

Antioxidant properties and phenolic content

Pulses contain many antioxidants like flavone glycosides, proanthocyanidins and flavanols[87], while catechins and phenolic acids are mostly present in the seed coat of pulses[88]. These antioxidants scavenge free radicals thus preventing oxidation of other molecules[89]. In the early stages of roasting, the total antioxidant content of pulses decreases due to the presence of thermo-labile polyphenols. As the roasting process proceeds, anti-oxidants products are further produced by the Maillard reaction such as melanoids[72]. These are also known as Maillard Reaction Products (MRPs). Reduction in water content during roasting aids in the production of these products. The final concentration of the antioxidants is regulated by the balance between the degradation of native anti-oxidants by heat during roasting and the production by MRPs[90]. If the Maillard reaction produces anti-oxidants at a greater rate than they are being degraded, then there is an overall increase in the concentration of the anti-oxidants.

Emulsifying properties

Protein being amphiphilic in nature can retain oil liquid medium[68]. These emulsions should be stable in nature to be used in food stuff like mayonnaise. Upon native heating structure of the protein changes, hydrophobicity is increased. As a result, solubility of the proteins decreased. Therefore emulsifying properties of proteins are inhibited upon roasting operations[96][50].

6.0 Roasting Equipment and Suppliers

1. Roast-A-Matic: - The company is manufacturing roasting equipment since 1972. They manufacture six types of roasters: Model 15, Model 50, Model 165, Model 400, Model 800, 5815SS salt dryer and custom roasters.
2. KMEC Engineering: - this company manufactures principally peanut roasters. Some of their products are: KL-3 Commercial Peanut Roaster, KL-5 Commercial Peanut roaster, HH Peanut roaster.
3. Buhler: - For roasters, it has several models: Vertical Roaster RoaStar™, Roasting system Tornado RSX, Roasting system Tornado RS, RoastMaster™ 120, RoastMaster™ 20, RoastMaster™ 60.
4. Fans Bro Erectors: - an Indian company established in 1996. They provide custom-made roaster specifically made for a given material. http://www.roastingmachine.co.in/
5. Shunmugam Pillai & Sons: - Established in 1956 in Andhra Pradesh, India. The company specializes in manufacturing roasters. Some of the product are: grain roasting machine, Multi-purpose grain roasting machine, cereals roasting machine, etc.
6. Xtreme MechXperts- This is a Coimbatore, India base firm that provides a wide range of grain and pulse toasters, with continuous as well as batch operating facilities.

7.0 Innovation

There is an evident need to develop processing strategies for innovative, versatile, and commercially-ready pulse ingredients for both the Canadian food sector and global market development.

The knowledge required will guide the food sector in identifying processing/milling strategies to achieve pulse flour/protein specifications with the required functionality and nutritional profiles needed for a wide range of food applications (as functional food ingredients and protein alternatives).

Globally, companies will be looking to diversify their ingredients through some level of processing to gain market share within the competitive food (protein) ingredient markets. The protein ingredient industry was worth $24 billion US in 2015 and is expected to grow by 7% from 2016-2024. The protein industry is seeking healthy, lower cost alternatives that could meet consumer and industry demand in the future. Pulse proteins may fit the bill for their nutritional value, their techno-functional properties, and for their availability at relatively low cost compared to the other protein sources on the market.

Currently available pulse ingredients are not exploited to their full potential as they have not specifically been processed for particular functionality or application. There is thus a need to:

- ✓ understand the physicochemical, functional and nutritional value of whole pulses, processed and milled flours;
- ✓ standardize characterization techniques for pulse quality assessment; and
- ✓ develop new pulse fractions designed for specific functionalities.

In reviewing the literature, it is evident that each combination of processing methods and pretreatment (soaking/nonsoaking followed by moist heating (infrared, steam, microwave, pulsed electric field, etc.) and dry heating (roasting techniques)) significantly affects the proximate and mineral compositions, amino acid profile, antinutrient content, protein solubility, in-vitro digestibility, and functionality.

Additional new product opportunities on roasting include:

- Extension of roasting to other pulses other than chick peas
- Pulse flakes with new flavors as snacks, breakfast cereals
- Germinated pulses followed by roasting to get a new variety of pulse flour
- Micronized flaked pulses as quick cooking pulses.
- Optimizing roasting condition to improve the aroma of pulse flour for bakery and confectionary applications
- Roasted pulse flours as protein and fiber ingredients in dairy products, spreads, yogurts, beverages, etc.
- Energy bars containing roasted pulses.

8.0 Commercial Products Available Globally Based on Pulse Roasting Technology

Globally there is a slowing growing product line based on roasted pulses. Being superior in taste, with greater shelf life, extended freshness, better sensory and rheological properties, these roasted and ready-to-eat pulse products are gaining demand in the market. Few examples of these products include:

- Hodmedod's British roasted fava beans and peas, roasted ready to eat peas (https://hodmedods.co.uk/).
- Pangkarra's Australian roasted chickpeas and bean mix in different flavors (https://www.pangkarrafoods.com.au/products/pulses/roasted-pulses).
- Ready to eat lentils in the UK from Merchant Gourmet (https://www.merchant-gourmet.com/)
- Three Farmers, an Ontario based firm produces roasted chickpea and pea snacks (http://threefarmers.ca).
- Frozen pulse salads in the US from Path of Life (http://www.pathoflifebrand.com/products/all-categories/) and St Dalfour (http://www.stdalfour.us)

9.0 Conclusion

Over the last decade, engineering, process, and technological innovation have pushed boundaries to develop modern and nutritious foods capable of addressing the great inequities facing society today. In the face of growing concerns regarding food security, environment, and healthy aging, pulses are the leading agricultural commodity with the highest potential for addressing these concerns. Today, processing strategies like roasting are capable of producing more appealing, nutritious, and affordable foods for consumers. Modern roasting methods, such as sand roasting, enable innovators to modify the characteristics of foods to better meet consumer demand, including nutrient (nutritional value and digestibility) and sensory (smell, texture, flavor, and appearance) profiles. In previous work, we found that consumer behavior can be predicted by a food products' color, taste, texture, nutrition, as well as related marketing aspects [97]. Within the context of the present study, we can use innovative processing technologies like roasting to modify the sensory and behavioral aspects of food to better address consumer preferences, while also contributing to individual and collective health and economic prosperity.

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