CHAPTER 1

INTRODUCTION

"Many of the items that we consider "waste" are culinary staples in other cultures because people have found a way to make them delicious through good cooking."

Chef Dan Barber

1. Introduction

1.1. Agricultural by-products

Agricultural by-products are the residual part generated after processing of certain agricultural products like cereals, legumes, fruits, vegetables. Production of such by-products exert imperative impression on various sectors like environmental, socio-economic sectors (Torres-León *et al.,* 2018). Improper discard of these by-products contribute to the generation of Green House Gas emissions (Girotto *et al.,* 2015). Management of large amounts of the agricultural by-products is a difficult challenge. In milling industries during processing of cereals, legumes, large amount of bran and husks are generated (Prabhakaran *et al.,* 2017). Fruit and vegetable by-products viz., peels, seeds, stems are also part of these agricultural by-products. These by-products which are the outer layer of grains, fruits, and vegetables, retain more nutrient and functional quality than their source (Ayala *et al.,* 2011). After the processing of citrus fruits (orange), used for producing juice, by-products like seed, pulp, peels are generated. According to the studies, these by-products are significant source of antioxidants and Vitamin-C as well as immunomodulatory components along with other beneficial bioactive compounds like flavonoids, carotenoids, phenolic, and limonoids (Wolfe & Liu, 2003). Polymethoxyflavones (PMFs) present in peel mainly showed the wide spectrum of immunomodulatory effect (Lin *et al.,* 2003), anti-obesity (Lai *et al.,* 2013), anti-inflammation (Gosslau *et al.,* 2014).

1.1.1. Rice and wheat by-products

Being the most-cultivated cereals, rice and wheat cultivation generates large quantity of by-products. Worldwide, especially in Asian countries, rice (*Oryza sativa*) and wheat (*Triticum*) are considered to be the most cultivated and consumed cereals in India and other

Asian countries (De Vasconcelos *et al.,* 2013). Production of rice (*Oryza sativa)*, is almost 600 million tons yearly (Chen et al. 2012). Though it is cooked and consumed to acquire nutrients along with caloric intake, a large part of nutrients in rice is almost lost due to removal of its milling products. This unconsumed fraction includes 20% rice husk, 8% rice bran and 2% rice germ (Kim et al. 2011). These by-products consist of phenol compounds in addition with other vitamins, minerals, fibre. Their low digestibility and low bulk density also make them consumable (Saha et al. 2008). Sitostanol extracted from rice bran showed reduction in cholesterol and low-density lipoprotein. Bran contains dietary fibres viz., beta-glucan, pectin, polyphenols, carotenoids, Vitamin E and many more essential micronutrient as well as macronutrients (Sookwong *et al.,* 2016). Acetylated steryl glucosides, 24-methylenecycloartenol ferulate, β-sitosterol ferulate, Tocotrienol etc. health beneficial steroidal compounds are also obtained from rice bran (Sookwong *et al.,* 2016). In case of Wheat bran, only 10% of it is being used in food industries (Hossain et al 2013) among 45 to 90 million tonnes global production. Wheat bran possesses dietary fibre, Vitamin B6, thiamine, folate, sterols, alkyl resorcinol, ferulic acid, lignans and many other crucial phytochemicals (Chakraborty and Budhwar, 2019). Fibre rich wheat bran includes arabinoxylan, starch, xylans which helps to maintain gut health (Deroover *et al.,* 2020). According to a study, incorporation of wheat bran in diet reduced serum cholesterol effectively (Chadha and Purohit, 2018).

1.1.2. Chickpea and moong bean by-products

Legume production also generates a large amount of by-products. These by-products, obtained from dhal milling industries are mainly used for animal feed. Chickpea (*Cicer arietinum* L.) is the third most cultivated (after dry beans and field peas) and consumed bean throughout the world (Chibbar *et al.,* 2010). Despite being highly nutritious (Niño-Medina *et al.,* 2019), chickpea (Garbanzo bean) husk did not get worth acceptance yet in the food industry, rather it is more used in the chemical industry, dye industry, as absorbent. Moong bean is another most cultivated and consumed legumes worldwide, especially in Asian countries (Tiwari *et al.,* 2011). Due to the presence of high fibre and essential micronutrients, the moong bean as a whole and even its outer skin (husk) are being used as a food source. Formulated products utilizing moong husk have shown potential nutrient content and bioactivity (Tiwari *et al.,* 2011). Value added products developed using these by-products might also contribute to enhance health status. These by-product-based products can be used as dietary intervention for weight management, hypertension, high blood pressure, diabetes, obesity and other metabolic disorders.

Bengal gram (*Cicer arietinum)* is one of those pulses that produce a large amount of useful agro waste from in dhal (pulses) milling industries mainly for animal feed. Chickpea (11.6 million tons) is considered as the fourth largest among global pulse production. Therefore, generation of by-products is also massive. This legume husk (86.6-88%) is very much rich in dietary fibres, protein (5.25%), minerals (Ca, P, Fe)**.** Dietary fibre mainly present in husk are cellulose, lignin, hemicellulose, gums, oligosaccharides, mucilages, and pectin (Sathyanarayana and Prashanth, 2019). According to previous researches, proximate composition of Bengal gram husk and cereal straw is comparable**.** Beside husk part, seeds, bran, straw are also gainful for consumption as human feeds. Though it contains a certain limit of anti-nutrients, it's manageable. Chickpea husk possesses non-digestible polysaccharides. Pectic polysaccharides extracted from the husk are generally used as additive in food industries (Sathyanarayana and Prashanth, 2019). Due to presence of high fibre, chickpea husk had been utilized as an innovative food ingredient to formulate pasta. This developed husk-based product showed high level of anthocyanins [In raw and cooked foods (on dry matter) 33.37±1.20 and 20.59±0.11 mg/kg of cyanidin-3-*O*-glucoside respectively]. Incorporation of husk also showed enhanced bioactive compound activity (Costantini *et al.,* 2021). Another study showed that the phenolic extract of chickpea husk had higher level of phenolic content and antioxidant activity. Husk polyphenols enhanced the activity of enzymes viz., catalase and glutathione peroxidase. Due to the enhanced activity of lysozyme, superoxide dismutase, catalase, and glutathione peroxidase content as well as antioxidant capacity, the study also depicted probable use of chickpea husk as innovative ingredient for the development of nutrient-dense foods (Akhtar *et al.,* 2020). Moong (*Vigna radiata*) is another large production of pulses, especially in India (almost 54% of World production). The bran and straw are also rich in protein. The mung beans hull comprises massive quantity of macro (protein, carbohydrates, polypeptides) and micronutrients (flavonoids, triterpenes, sterols, aldehydes, phenols), that exhibits effective biological activities (Akhtar *et al.,* 2020). Based on different nutritional and anti-nutritional aspects these by-products of cereals and pulses could be utilized efficiently as human consumption along with animal feed. Ash content, crude fibre, crude fat and protein, dietary fibres, total minerals, phenolic contents, glycemic index, physicochemical properties etc are the main aspects to be considered to use bran, straw, husks to develop food stuffs to combat present malnourish conditions in cheap prices along with a designed future projection to avoid challenging hunger issues and shortage of food by perfectly using agro-wastes of crops.

1.1.3. Health benefits of agricultural (Milling) by-products and prevention of diseases

Preservation and utilization of these milling by-products for longer use can be a significant approach against hunger, food demand, and malnourishment for the benefit of the developing countries (Chakraborty and Budhwar, 2019). Due to their health benefits though some milling by-products are achieving the attention, some are yet to reach that mark due to lack of proper dissemination of knowledge about their potential. The milling by-products of rice, wheat, moong bean, and garbanzo bean were chosen due to their higher production level and popularity worldwide with the aim to spread more awareness and knowledge about the impact of the milling by-products as an alternative food source.

Milling by-products of rice can improve many diseased conditions viz., hyper cholesterol, degenerative diseases. Their antioxidant properties are also advantageous in oxidative damages as they consist of high intensity of flavonoids, hydrocinnamic acid derivatives, phytic acid etc. Sitostanol extracted from rice bran showed reduction in cholesterol and low-density lipoprotein. Oryzanol present in bran inhibits cellular oxidation (Sookwong *et al.,* 2016). Phytochemical rich wheat bran reduce risk of fatal diseases viz., cardiovascular diseases, diabetes, cancer, metabolic disorders. It includes arabinoxylan, starch, xylans which helps to maintain gut health (Deroover *et al.,* 2020). Incorporation of wheat bran in diet reduced serum cholesterol effectively (Chadha and Purohit, 2018). Besides cereal by-products, pulse by-product-based products can be used as dietary intervention for weight management, hypertension, high blood pressure, diabetes, obesity and other metabolic disorders. Polyphenols, extracted from chickpea husk, downregulated the production of inflammatory markers like interleukin-6 (IL-6) and nitric oxide (NO). Based upon the data, it was concluded that phenolic extract of chickpea husk can mitigate oxidative stress as well as inflammation by regulating pro-inflammatory markers and antioxidative enzymes which are linked to chronic inflammation (Mahbub *et al.,* 2021). Immunomodulatory activity of chickpea husk was observed where polysaccharides present in husk was responsible for improved immune activity. Major bioactive compounds found in moong bean husk were gallic acid, ferulic acid, sinapic acid, vitexin and isovitexin (Basha and Rao, 2017) that exerts effective antioxidant property.

1.2. A review on agricultural by-products: Nutrient composition, health benefits, food formulation and storage stability

Rapid global population growth with increasing food demand has been depicted in several studies. According to those portrayals, without significant policy interventions, by 2050 an issue of food shortage may appear (Alexandratos and Bruinsma, 2012). Thus, researchers and food specialists worldwide are keen to find substitute food sources, especially plant-based food alternates along with preservation of traditional greens and lowering "Food loss". The term 'Food loss' refers to the food that is available for consumption but gets wasted or unconsumed (Buzby *et al.,* 2014). Therefore, besides stunting of foods, huge post-harvest losses also contribute to food loss. It has been estimated that by the year 2050, global population will reach 9.1 billion indicating an additional food requirement of 70% to avoid issues like hunger, malnourishment, crop shortage, etc. (Montagnini and Metzel, 2017). The developing countries have already taken initiatives to increase agricultural production and viability along with understanding the knowledge of post-harvest loss (PHL) and their probable utilization in food industry.

PHL is a broad area of agriculture and agricultural by-products such as milling by-products are also considered as a part of post-harvest loss. These milling by-products (Table 1.1**)** are generally used for livestock feed, biogas production, and composting, in spite of possessing enormous amount of nutrients. These by-products are generally dumped in the field and burned or kept stacked in landfills**.** There is a 5% annual increase in the rate of waste generation in India contributing an estimated 42 million tons of municipal garbage annually. There are almost 1000 million tons of milling by-products produced globally. The quantity of these by-products is different in various countries depending on crop varieties and the amount of land available for farming (Manna *et al.,* 2018).

Sources	By-products
Rice, Wheat, Oat	Bran, hull
Wheat, Oat	Straw
Chickpea	Husk
Black gram	Husk
Sugarcane	Sugarcane tops, bagasse, molasses

Table 1. 1: List of by-products and their sources (Tsadik and Emire, 2015).

In addition to the assortment of food alternates, it is also essential to look into the matter of shelf life of these sources and formulated food products from them. Preservation of foods and their sources is one of the primary goals in the field of food science. Contamination of the agricultural products and the plant-based foods in various circumstances is always distressful. Moreover, presence of fungus (*Aspergillus, Alternaria, Penicillium, Fusarium* genera) results in mycotoxin contamination leading to poor quality of food (Heshmati *et al.,* 2017; Khaneghah *et al.,* 2020). Mycotoxin contamination is mostly found in crops (Arzani and Ashraf, 2017). There is a high chance of contamination at different stages of the harvest and post-harvest of cereals and legumes. Thus, various decontamination processes such as chemical processes, physical processes, and irradiation are employed to diminish microbial loads in cereals, legumes, and formulated foods (Los *et al.,* 2018). Preservation and utilization of these milling by-products for longer use can be a significant approach against hunger, food demand, and malnourishment for the benefit of the developing countries (Chakraborty and Budhwar, 2019). Due to the health benefits though some milling by-products are achieving the attention, some are yet to reach that mark due to lack of proper dissemination of knowledge about their potential. For this study, the milling by-products of rice, wheat, moong bean, and garbanzo bean were chosen due to their higher production level and popularity worldwide with the aim to spread more awareness and knowledge about the impact of the milling by-products as an alternative food source.

The milling process improves the nutritional value, cooking time, and sensory attributes of crops. One, two and multi-stage milling are the three milling procedures (Bodie *et al.,* 2019). The by-products generated from this process is believed to have a significant impact on food sustainability. Valorisation of these by-products as an alternative source in food industries, would, certainly support the researchers to approach a step towards their search of substitute food source and sustainability of agricultural production. These milling by-products are found to be rich in beneficial phytochemicals. The by-products can be processed to formulate food products (Bodie *et al.,* 2019). Use of these underutilized by-products as nutraceutical ingredients in the food formulation has been initiated and commercialized among several communities. These nutrient-rich sources in our daily diets can be a boon to a healthy lifestyle.

1.2.1. Nutrient composition and the bioactive properties of the milling by-products

1.2.1.1. Rice Bran

Rice (*Oryza sativa*) is considered as the major cereal consumed as staple food worldwide, especially in Asian countries, viz., India, Bangladesh, Japan, Indonesia etc. (Raghav *et al.,* 2016, Maraseni *et al.,* 2018). Different variants of rice production occur in more than 100 countries globally, which cover almost 25% of whole food grains production universally (Prasad *et al.,* 2017). When paddy rice is milled, it generates about 70% of rice along with husk, bran (outer layer of rice), and germ (Hoogenkamp *et al.,* 2017). During this de-husking process, a brown portion of rice is drawn out as fine grains which are known as rice bran (Aung, 2017; Gul, 2016).

Rice bran comprises of two parts known as aleurone and pericarp. It contains a wide range of micronutrients like oryzanols, tocotrienols, tocopherols, phytosterols, 15% protein, 20% oil and 50% carbohydrates (Table 1.2). The bran also contains other dietary fibres (Table 1.2) like beta-glucan, pectin, and gum (Özer and Yazici, 2019; Thomas *et al.,* 2016). Dietary fibre in diet can prevent the risk of diabetes, metabolic diseases, definite gastrointestinal diseases, cardiovascular diseases and enhance gut health leading to improved immunity (Watzl *et al.,* 2005). Rice bran was generally used as animal fodder but later its usage has extended to food industry and many more (Asmare and Yayeh, 2018). It has been reported that India and Thailand are the two main countries that produce a major part of the global rice bran oil (Lai *et al.,* 2019). An amount of 6.5 lakh tons of rice bran oil was obtained from 40 lakh tons of rice bran via the solvent extraction method (Satlewal *et al.,* 2018). Different varieties of coloureded rice yield rice bran in significant amounts and they possess various antioxidants viz., polyphenols, carotenoids, vitamin E, and tocotrienol (Sookwong *et al.,* 2016).

Chemical characteristics	
Ash (%)	19.17
Moisture (%)	1.27
Physical properties	
Water binding capacity (WBC) (ml/g)	8
Oil binding capacity (OBC) (ml/g)	3.5

Table 1. 2: Physicochemical properties of dietary fibre obtained from rice bran (Gul *et al.,* 2015)

Parameters (g/100 g)	**Bran**
Moisture	12.1±0.25
Protein	12.3±0.24
Fat	20.3±0.92
Ash	8.7±0.08
Digestible carbohydrates	17.9±0.26
Dietary fibre	28.6±0.32

Table 1. 3: Nutrient composition of rice bran (Gul *et al.*, 2015)

Stabilized rice bran consists of different vital compounds (Table 1.4) at a large range of concentrations that help to withstand chronic diseases. There are some minor components present in rice bran, like, gamma oryzanol (Figure 1.1), phytosterols and conjugates, which show antioxidant activity with a huge potential against toxic free radicals (Perez *et al.,* 2017).

Various studies suggested that gamma oryzanol present in rice bran is more efficient than Vitamin-E to inhibit the oxidation (Kanchi *et al.,* 2017). Due to presence of certain components, incorporation of rice bran in diet can help to manage cholesterol and heart disease risks (Borresen *et al.,* 2017). The bran acts as a salient functional food that also possesses antineoplastic properties (Arun *et al.,* 2020). Scientific studies suggest that soluble sitostanol obtained from rice bran when supplemented in human diets, the level of circulating cholesterol and low-density lipoprotein (LDL) got significantly reduced by 7.5% and 10%, respectively. Dietary phytosterols increased the lecithin-cholesterol acyl transferase (LCAT) in the blood, which helps in seclusion of cholesterol within the hydrophobic core of the high-density lipoprotein (HDL) type (Borresen *et al.,* 2017). Phytosterols have the property of lowering cholesterol reported since a long time back. Many studies suggest that the action of beta-sitosterol and sitostanol present in rice bran helps in lowering LDL and the circulating level of cholesterol, which indicates their activity as a hypolipidemic agent in mild hypercholesterolemia. It also alters the metabolism of lipids, like minimizing liver acetyl co-acarboxylase exhibited by malic acid (Borresen *et al.,* 2017; Issara and Rawdkuen, 2016). Gamma-oryzanol present in rice bran oil (RBO) shows hypocholesterolemic effects at high and low concentrations. Consumption of gamma-oryzanol for a period of 4 weeks decreased total plasma cholesterol by 6.3%, LDL-C by 10.5%, and the ratio of LDL-C / HDL-C by18.9% according to a study (Borresen *et al.,* 2017).

Intake of dietary fibre present in rice bran diminishes the risk factors of coronary heart disease (CHD) mortality rate with reduced blood pressure and enhanced insulin sensitivity (Saji *et al.,* 2019).

Ferulic acid hydrolyses gamma oryzanol in the intestine resulting in the precipitation of dietary cholesterol. All these mechanisms lead to cholesterol excretion. (Perez *et al.,* 2017; Alam, 2019). It was also reported that phytosterols exhibit the property of tumour inhibition, which are due to the induction of chemical compounds such as secondary bile acids in the animal body. For example, secondary bile acids aid in colon cancer development. The compound oryzanol (Figure 1.1) present in rice bran helps in protection against UV light by preventing lipid peroxidation (Figure 1.2). Ferulic acid and esters, which are found in gamma-oryzanol revitalize the hair growth and prevents skin aging (Mohiuddin, 2019).

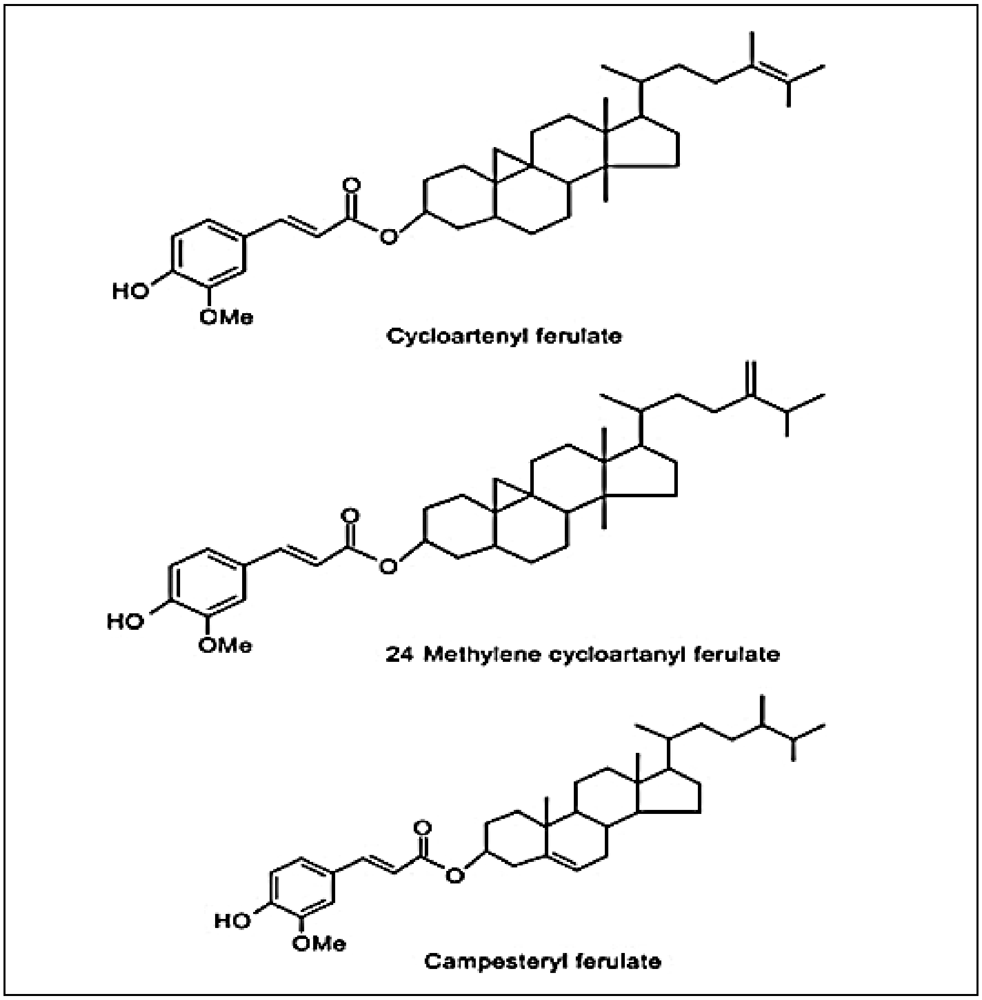

Figure 1. 1: Three major components of gamma oryzanol obtained using GC/MS (Srikaeo, 2014; Xu and Godber, 1999)

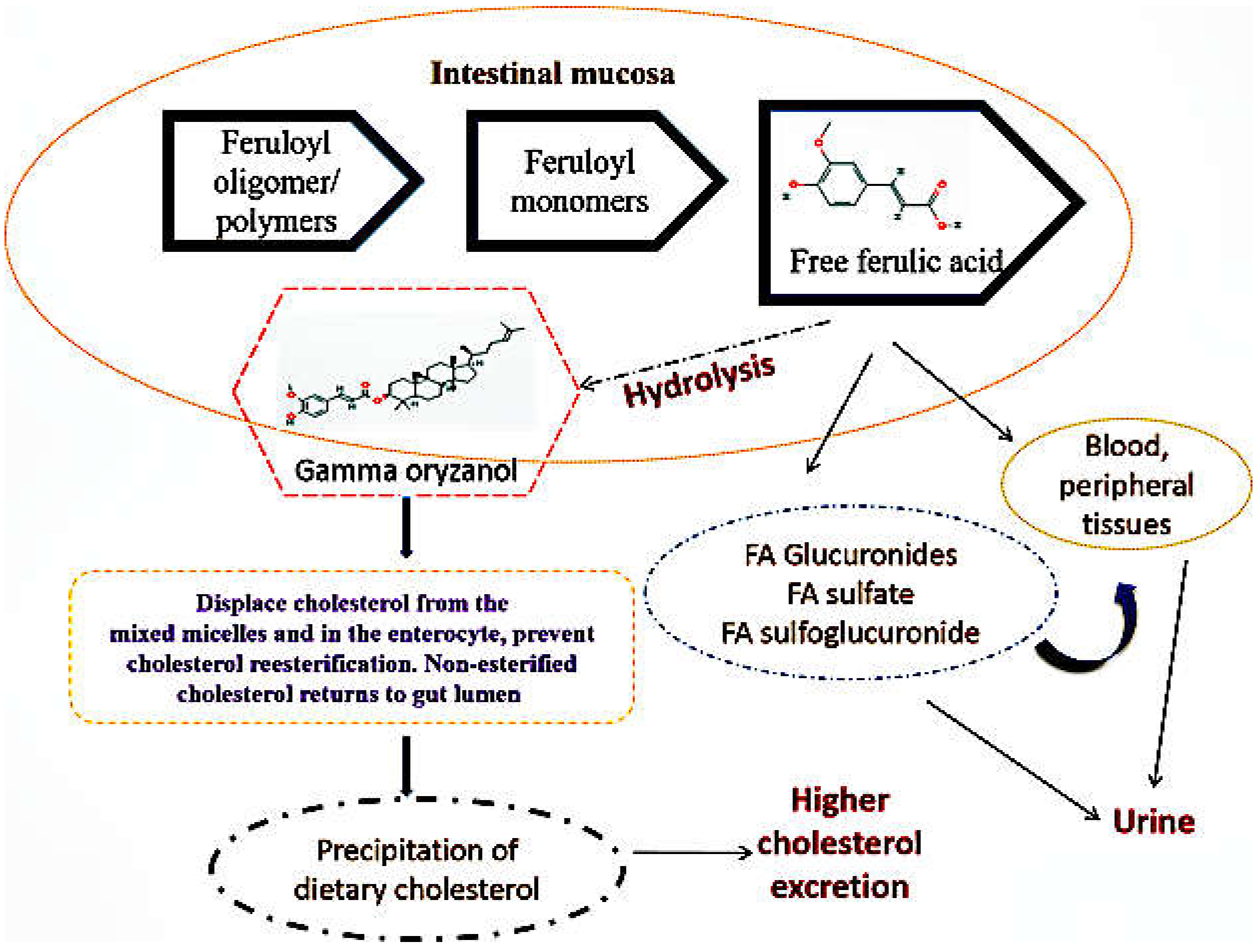

Figure 1. 2: Role of ferulic acid and gamma oryzanol in lipid lowering mechanism of rice bran.

1.2.1.2.Wheat bran

Wheat is considered to be the second major cereal consumed by almost one-third of the world's population (Onipe *et al.,* 2015). The commercially viable two major varieties of wheat are *Triticum aestivum vulgare* and *Triticum turgi dumdurum*. Later is also known as hard wheat, which is mainly used in the preparation of pasta products. Both of the varieties are of utmost importance as they have wide applications in the preparation of bread, biscuit production, different confectionary items, and vital wheat gluten. Its usage is also found in the brewing industry as a raw material to produce ethanol and white beer. Wheat protein is believed to be a significant substitute for meat and wheat straw is used as composites as well as cattle feed (Su *et al.,* 2017). Being a potent source of protein, vitamins, minerals, and dietary fibre, wheat (Onipe *et al.,* 2015) cultivation occurs in China, India, Russia, USA, France, Canada, Germany, Pakistan, Australia, and Ukraine and their joint net production amount was 760 million tons in the year 2017 (Tian *et al.,* 2017). India holds the second position amongst the largest wheat-producing countries in the world producing a wholesome amount of 95 million metric tons to 100 million metric tons (Abbasi and Abbasi, 2016). Wheat grain is also known as caryopsis which is mainly used for human consumption. Its length lies between 5-9 mm and weighs between 35 and 50 mg. The bran covers 13-17% of the whole grain, germ or embryo covers 2-3% while the starch-filled endosperm portion covers 80-85% (Xia *et al.,* 2019).

The conventional milling is based of separation of endosperm (the source of white flour) from the embryo and the bran layers (Onipe *et al.,* 2015). The bran is formed with the aggregation and after removal of aleurone cells along with other bran layer composites. Processing is done to monitor the palatability, food safety, and bioavailability of different nutrients. The potent health beneficial factors and high dietary fibre rich food products are drawing a deep interest for a long period for last several years (Xia *et al.,* 2019). Bran also contains vitamin B6, folate, thiamine, vitamin E, sterols, phenols, alkyl resorcinol, carotenoids, ferulic acid, lignans (Chakraborty and Budhwar, 2019; Budhwar *et al.,* 2020). A global report suggests an increase in the number of wheat bran-containing products, which range from 52 in 2001 to approximately 800 in 2011. Thus, it can be conferred that increasing awareness among society for healthy foods is leading to the growth of organic food market (Nazir *et al.,* 2019). Wheat bran is mainly used in the formulation of food types viz., bakery, roasted, fried for the last few years (Prueckler *et al.,* 2014). Extraction of wheat bran occurs via two main processes, viz. dry milling and roller milling. Dry milling consists of the process of segregation of bran and obtain fine flour while roller milling involves the efficient achievement of wheat bran by its separation from wheat grain (Miskelly and Suter, 2017). Other processes involved in the removing of bran from the wheat grain are peeling, bran fractionation, and pearling resulting in elevated nutrients (Babu *et al.,* 2018).

Intake of wheat bran helps in reducing total serum cholesterol (Chadha and Purohit, 2018). According to a study report, when a wheat bran based breakfast was consumed by some participants affected by the highest quintile of serum cholesterol for 3 weeks, the level of serum cholesterol was lowered to 4.385 mmol/l from 5.576 mmol/l. The vital HDL-C did not get affected and this supports the safe consumption of wheat bran possessing multiple beneficial efficacies (Katileviciute *et al.,* 2019). Wheat bran also can reduce the symptoms of irritable bowel syndrome (IBS) (Babu *et al.,* 2018). Even an increased consumption of dietary fibre present in wheat bran reduces the risks of bowel cancer including colon cancer in human beings by almost 40%. Wheat bran consumption with the supplementation of ascorbic acid and α-tocopherol or without the supplements for a continuous period of 4 years helps in the reduction of polyp number and the possibilities of getting affected by cancer also get reduced (Babu *et al.,* 2018). Some reports suggested that wheat bran-supplemented diet at an amount of 13.5 g/day significantly reduced the concentration of bile acids that acts in causing colouredectal cancer (Deroover *et al.,* 2020). Colon carcinogenesis was reduced and the chances of developing tumors also lowered as part of the effect of wheat bran.

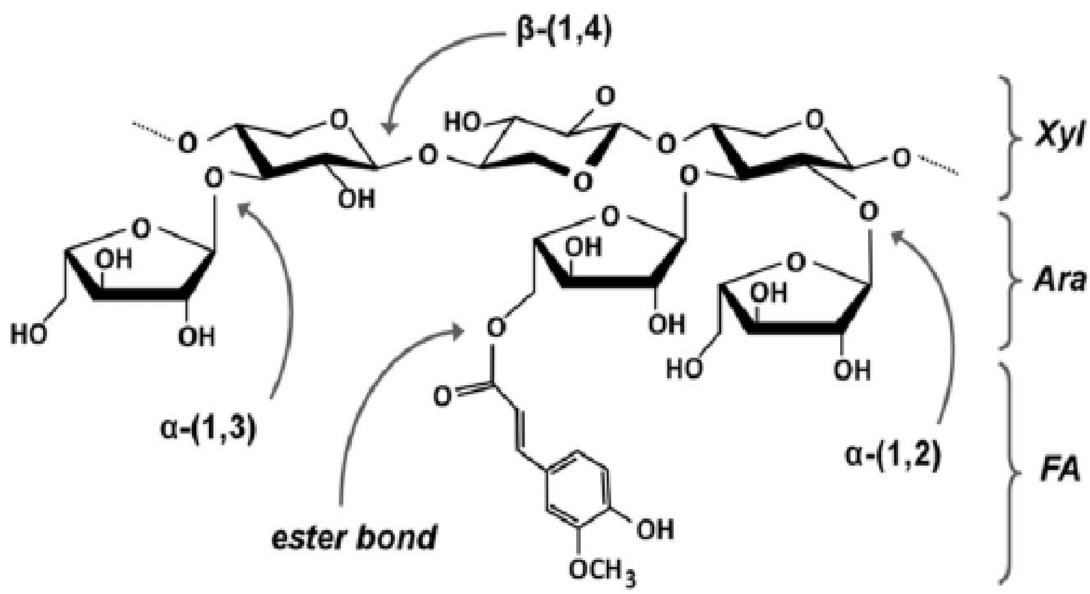

Figure 1. 3: Structure of ferulic acid bound to the arabinoxylan complex present in wheat bran (Zhao *et al.,* 2018)

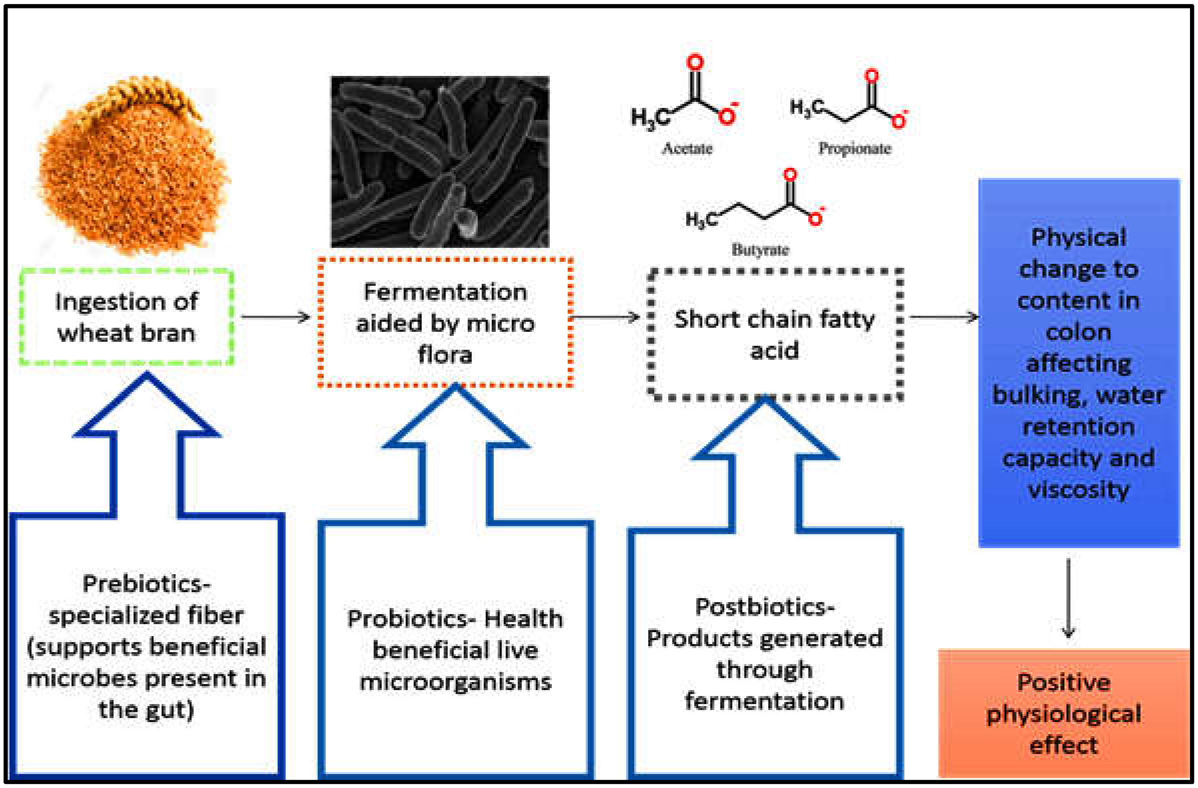

Figure 1. 4: Role of wheat bran as prebiotic in fermentation process

Wheat bran, when fermented into short chain fatty acids aided by microflora residing in the intestine results in physical changes to the contents of the colon, which in turn affects bulking and water retention capacity (Babu *et al.*, 2018). Wheat bran is an important source of prebiotics, which are generally the food ingredients of non-digestible nature that benefit the host through selective stimulation of growth of micro florae in the colon (Babu *et al.*, 2018; Gunenc *et al.*, 2017).

1.2.1.3. Chickpea husk and moong bean hull

Chickpea (Garbanzo bean/ Bengal Gram) (*Cicer arietinum)* is one of the most popular and sold out pulses. Chickpea production rate stands fourth among the pulses all over the globe and its production is 11.6 million tons (Sofi *et al.*, 2020). Due to the large production, generation of enormous amount of milling by-products is also inevitable. Generally, the chickpea by-product (husk) end up as parts of animal feed. Lack of proper knowledge dissemination and novel processing strategies might be a reason that the probable use of this husk in food industry is still under struggling mark in comparison with the by-products of rice and wheat.

This legume husk (86.6-88%) is rich in dietary fibre, protein (5.25%), and minerals (Ca, P, Fe). According to researches (Oghbaei and Prakash, 2016), the nutrient contents of Chickpea husk (Table 1.5) and cereal straw are comparable. The major by-product is the straw part of chickpea. Its digestible nutrient content is almost 44-46% along with 4.5-4.6% protein, dry matter (DM) basis. Based on comparative studies, it had been shown that the chickpea straw is more nutritive than other legume seed straws (Raju *et al.,* 2018). A novel antioxidant present in the husk is methoxy pectin in low levels and is related to galacturonic acid content (Nithya *et al.,* 2016). Though it contains a certain level of anti-nutrients, it is manageable by using various pre-processing treatments such as blanching or extrusion (Liu, 2018).

Moong (*Vigna radiata*) is another largely produced pulse, especially in India with almost 54% of global production (Shrinivasa and Mathur, 2020). The straw bran is rich in protein. Moong bean hull contains high levels protein, oligosaccharides, flavonoids, phenols, sterols that exert antioxidant activity (Rosy *et al.,* 2017). Moong bean bran, the most important and rich source of protein (19.2%, dry matter basis), is also known as chunni/ churi (in India) and contains a partial portion of husk along with broken pieces of endosperm including the germ.

Approximately 50% of this bran production is used for livestock feed (Shrinivasa and Mathur, 2020). The outer covering part that is the seed coat is also utilized as animal feed, despite being a unique source of crude protein (12%, dry matter basis) and crude fibre (19%, dry matter basis) (Shrinivasa and Mathur, 2020). Legume straws are much more protein-rich compared to cereal straws and moong bean straw is not different (9-12%, DM basis). Moong bean husk also contains a large amount of fibres as partially insoluble, which is healthy for the gastrointestinal environment in relieving constipation (Rosy *et al.,* 2017).

1.2.2. Formulated food products from the selected by-products

1.2.2.1. Rice Bran

Use of rice bran in food formulation as a nutraceutical product is well known (Zheng *et al.,* 2019). Based upon the scientific reports, dietary fibre-rich rice bran has been used as a food additive that exerts its laxative function (Sohail *et al.,* 2017). Another study reported that rice bran addition increased muffin volume though bread volume and cookie spread were decreased (Jung *et al.,* 2020). The report also stated that 5-10% rice bran could be used for the formulation of different food products (Jung *et al.,* 2020). During the process of rice bran oil extraction, an amount of wax (Rice bran wax) is also obtained due to refining. Other than the food industries, potential application of rice bran wax has been found in pharmaceuticals, leather, cosmetic, and polymer industries (Kumari *et al.,* 2019).

1.2.2.2.Wheat Bran

Wheat bran is considered to be an efficient ingredient in the recipe of healthy foods (Onipe *et al.,* 2015). It was reported that on adding wheat bran in pasta, the colour of pasta became dark, and there was a rise in water absorption along with the reduction in cooking time (Onipe *et al.,* 2015). Various studies also suggested that foods fortified with wheat bran have enhanced fibre content and optimum sensory attributes. Wheat bran when added into a probiotic containing feta cheese improved the viability of probiotic cells and considerably affected the volatile compounds leading to good quality feta cheese (Terpou *et al.,* 2018). Lauková et al. (2019) reported that cookies containing treated wheat bran were considerably softer than cookies incorporated with raw wheat bran. Sensory evaluation of these cookies revealed that the incorporation of stabilized wheat bran enhanced the overall shape and taste of the product. This study also showed that pre-treatment of wheat bran using different methods may enhance the qualitative properties of cookies such as hardness, texture, and volume.

1.2.2.3.Chickpea husk and moong hull

Pulses are considered as nutritious ingredients for food formulation due to their significance as a food source and their genotypic and phenotypic diversity. Various by-products generated from pulses were traditionally discarded by industries and producers. However, these by-products are now gaining various interesting applications due to the considerable number of essential phytochemicals present in them with enormous health benefits. Pulse by-products not only have the potential to reduce food insecurity as new sources of food but also mitigate various health states, which directly influence the economy and health systems (Campos-Vega *et al.,* 2020).

Developed food stuffs and components	Additional benefit due to presence of rice bran
Pizza (Dietary fibre rich stabilized rice bran flour)	Dough made up was at good condition throughout 2 months at -18ºC
Gluten-free bread (Dietary fibre fraction of rice bran)	Improved quality with increased sensory score and prolonged shelf life.
Pan bread (Defatted)	Product showed improved quality (crumb and crust) with higher level of fibre and mineral.
Bread	Loaf volume was increased in case of full fat and the volume was decreased after use of defatted rice bran.
Cookies (Rice bran fortified wheat flour)	Lysine and dietary fibre levels were elevated.
Defatted rice bran based Banana muffins, peanut butter cookies	Low fat high fibre products.
Cookies (Rice bran)	With the increased amount of added rice bran, average width, thickness and spread factor were enhanced. Supplemented percentage of heat stabilized rice bran was 10%.
Cookies (Defatted rice bran)	Improved dietary fibre content and mineral levels. According to the observation, 20% substitution in wheat flour can be done.
Pasta (Rice bran)	Higher dietary fibre, protein content and acceptable sensory scores up to the level of 15% of rice bran.

Table 1. 4: Formulation of value added food products utilizing rice bran (Gul *et al.*, 2015)

Incorporation of moong husk in several different traditional food recipes such as bread, muffin, pakora, biscuit, and mathri in different proportions enhanced the fibre content of the products. Moreover, moong husk incorporated food recipes has been reported to have a low glycemic index, appropriate for consumption by diabetic individuals (Bora and Kulshrestha, 2015). This fibre-rich moong husk based food products also found to be effective against constipated patients while additional benefits include blood cholesterol reduction. One study also reported that products having moong bean husk were well accepted by consumers when the sensory evaluation was done.

Chickpea husk addition to flours to prepare noodles resulted in considerably higher values of protein and dietary fibre in the product (Bora and Kulshrestha, 2014).

Incorporation of chickpea seed coat into dosa, a fermented food showed higher nutritional value, fibre content and antioxidant activity as compared to the dosa without chickpea seed coat. Beniwal and Jood (2015) reported that pulse milling by-product, when incorporated into different food products, showed antioxidant activity and inhibitory action towards advanced glycation end products (AGEs), which help to reduce the severity of complications associated with diabetes.

1.2.2.4. Sensory acceptance of the value added products

Mishra and Chandra (2012) portrayed the observation regarding the sensory parameters of developed products using rice bran and soy flour which was satisfactory and acceptable, although with sensory scores of the value added product got low with increased substitution of rice bran. Wheat bran in product formulation (Sozer *et al.,* 2014) also showed the same pattern. The major aim of the studies was to understand the acceptability of novel products in market to use as a supplement of health beneficial nutrients to minimize the occurrence of malnutrition. Bose and Shams-Ud-Din (2010) also disclosed that the pre-treated chickpea husk based crackers showed rich nutrient availability along with satisfactory sensory score indicating probable use of by-products as innovative food source.

1.2.3. Stabilization of milling by-products and by-product-based food products

According to studies, several approaches have been developed to improve shelf life of the formulated food products from the milling by-products. Either the by-product is stabilized before to avoid spoilage and then utilized for food formulation or after product preparation, it can be processed using various processing techniques (Table 1.4) (Yu *et al.,* 2020). The presence of lipase enzyme produced via microbial activities during the milling process makes the bran susceptible to rapid spoilage and short shelf-life that could make it unsuitable for ingestion. Thus, stabilization of the bran is very much needed (Yu *et al.,* 2020; Ling *et al.,* 2019). Lipase enzyme hydrolyses oil into glycerol and free fatty acid to impart a putrid odour and acrid taste that makes the product unacceptable for human consumption. The scientific report suggests that, under normal milling conditions, degradation of bran occurs within approximately 6 hours and it turns into unpalatable material unsuitable for human intake and thus the maximum portion of bran is utilized as a protein additive in cattle feed or for agricultural purposes such as for fertilizer or as fuel for household needs. There are plentiful methods to stabilize the bran viz., cold storage, steaming, sun-drying, and expelling. The chemical stabilizer used for this purpose is sodium meta-bisulphate (Yu *et al.,* 2020). Another processing technique in stabilizing rice bran is through the use of ohmic heating (Bhat *et al.,* 2018). Another method involves the addition of antioxidant-rich ascorbic acid, ascorbyl palmitate, and phosphoric acid or their admixtures to the food product for storage up to 6 months at ambient conditions (Bhat *et al.,* 2018; Banerjee *et al.,* 2017).

Stabilization methods	**Applied treatment**		**Effect on biological mechanisms**	**Impact on nutrients**
Physical methods	Stored at low temperature; refrigeration		Inhibition of lipase activity	Delay of nutrient degradation
	Heat treatment	Dry heating	Inactivation of lipase through loss of moisture present in bran	Observed increased protein, oil content along with thiamine level. No effect on total mineral content. Delayed formation of acidic compounds viz., free fatty acids (FFA) and peroxides in addition to increased content of γ-oryzanol.
		Moisture heating	Annihilation of lipase activity through utilization of both heat and moisture	Increased levels of γ-oryzanol, tocotrienol and tocopherol were observed with lower FFA.
		Microwave heating	Quick transfer of heat to the bran leading to inactivation of lipase through elevation of temperature.	Enhanced levels of minerals, proteins and bioactive compounds such as tocols, phytosterols and policosanols. Oil extractability was improved. Lower levels of dietary fibre and nitrogen free extracts.

		Ohmic heating	Lipase inactivation through heat energy generation	Reduced level of FFA formation and lipid oxidation.
		Infrared radiation heating	Heat generation through application of radiation energy to dry the bran resulting in inactivated lipase activity.	α-tocopherol, γ-oryzanol levels were higher along with total phenolic compounds, greater antioxidant activity. Due to covalent bond breakage, few phenolic compounds got released into their free state, such as hydrocinnamic and hydroxybenzoic acids.
		Extrusion	Lipase and peroxidase enzyme inactivation through application of either of the high degree of temperature, pressure, shear force.	Increased level of total dietary fibre. Denaturation and degeneration of protein resulted into reduced protein. Reduced Phytic acid and vitamin E with no change in Vitamin-B Group.
		Sub-critical water technique	High temperature (120-240ºC) to inactivate lipase activity.	Increased yield of oil extraction.
Biological methods	Treatment with enzymes		Damage of bran matrix due to application of enzymes.	Increased content of soluble fibre. High γ-oryzanol and α-tocopherol along with antioxidant property. Generation of short chain fatty acids in the gut leads to enhanced probiotic activity.
Chemical methods			Inhibition of lipase activity through adjustment of pH of	Less lipid oxidation

		rice bran by exterior chemicals.	
Combined methods	Microwave packaging +storage temperature	Resulted in destruction of lipase or inhibition of its activity.	Improved availability of extractable protein, fat and minerals (phosphorus, iron)
	Microwave and probiotic treatment + steamed with α-amylase + fermented with lactic acid bacteria + hydrolysed with complex enzymes		Lactic acid bacterial fermentation resulted in the formation of phenolic esterase and carbohydrase leading to improved antioxidant activity. Addition of glucoamylase, cellulase and protease caused destruction of cell wall matrix resulting in increased availability of phenolic compounds, especially flavonoids.

Table 1. 5: Methods of stabilization of the milling by-products (Liu *et al.*, 2019)

1.3. Food irradiation

In addition to the chemical and physical techniques, gamma irradiation is the another preferred process by several researchers to minimize post-harvest losses (Ryan *et al.,* 2008). Nowadays food irradiation is gaining popularity in many countries and the awareness regarding the process is increasing among the consumers. Therefore, to understand the trend, in this current study, apart from other shelf life enhancing methods, a brief review of food irradiation using gamma radiation also had been accomplished in the following contexts.

Food formulation is not the final step of a 'Successful product development process'. It is necessary to see how many days or the duration they will be spoilage free. Use of food irradiation technology instead of using chemical preservatives to enhance the shelf-life of the products is considered as cheap and safe as compared to other methods (Handayani and Permawati, 2017). The food irradiation technique was declared safe by FDA (Food & Drug Administration) (Handayani and Permawati, 2017). According to studies, doses used in irradiation process can only kill microorganisms. The used dose is not harmful for human body. Moreover, chemical preservatives remain in food, it doesn't escape. But, used dose of radiation is given in a way so that it escapes from food after a certain period of time to cease the contamination during transportation of the food (Handayani and Permawati, 2017, Ryan *et al.,* 2008). Bread and cookies can get deteriorated due to microbial deterioration (Ryan *et al.,* 2008) which affect the food market due to increased disposal of food products for foul smell. The fungus also leads to production of harmful substances such as mycotoxins (Dalié *et al.,* 2010). The fungal deterioration of wheat bread (Dalié *et al.,* 2010) is mainly caused by Penicillium species (Legan and Voysey, 1991). Another common fungus affecting the bakery products is Aspergillus, Mucor, and Cladosporium (Legan 1993).

Although chemical preservatives e.g. sorbic, propionic, and acetic acids as well as their salts can be used to control the deterioration of bread and cookies, use of these preservatives are not preferred due to their adverse effect on health (Dalié *et al.,* 2010). Beside enhancing the nutrition value, preservation of the formulated products is also crucial for longer use. Fumigants like ethylene dibromide (EDB) for agricultural products became debatable due to health concerns and side effects of some of those chemicals are found to be carcinogenic (Gould 1996). In contrast, application of ionizing radiation such as gamma radiation at a low dose was found to be suitable for food preservation (Jan *et al.,* 2020). Nowadays food irradiation is gaining popularity in many countries and the awareness regarding the process is increasing among the consumers.

In today's life, increasing demand for cost-effective nutritious food formulated from organic ingredients without any chemical preservatives is an indication of modernization and growing health awareness of society. Besides health concerns, enhanced shelf-life is another challenge nowadays and irradiation technology is found to be efficient as well as effective to face this challenge. Irradiation in the industry for food preservation can be a potent alternative to process postharvest mass without utilizing any chemical substances (Jan *et al.,* 2020).

Irradiation technique can enhance the shelf-life of processed food, retaining the nutrients in the food product which does not affect the sensory scores (Indiarto and Qonit, 2020). Besides preserving foods, this technology can also sterilize certain food products and maintain food security (Garcia and Copetti, 2019). Though due to lack of proper scientific education about the use of radiation some communities still consider only the negative aspect of radiation and nuclear technology, the irradiation process is energy-efficient and environment friendly (Handayani and Permawati, 2017). Effect of the radiation on any product depends on the composition and structure of the exposed product along with the energy of the gamma source. The interaction of radiation with the product can be understood through Attenuation Coefficient and absorbed energy. Attenuation Coefficient describes the relative decrement in the intensity of radiation passing through the absorber (product). If the absorber is relatively transparent, we will get small values of attenuation coefficient whereas large values of attenuation coefficient reflect the opacity of the absorber (Calado *et al.,* 2020).

According a study, 3kGy gamma radiation can cease the microbial growth in smoked salmon without affecting the sensory property of the food. Based upon the type of target to be accomplished permitted dose of radiation is determined. 1 kGy is sufficient to inhibit germination and delay in the ripening. Whereas, to destroy pathogens radiation of almost 1-10 kGy is needed. Higher dose (10kGy) of radiation is implied for the process of sterilization and decontamination. Though dose ranges are mentioned in previous studies, they cannot be used as a defined measure because radiation doses might differ depending upon the surroundings. Gamma radiation upon food products also eliminates toxic elements like mycotoxins (Calado *et al.,* 2020). The effect of gamma radiation on Zearalenone was studied to determine the cytotoxicity as well as the estrogenicity after the application of gamma radiation (Calado *et al.,* 2020). Reduced cytotoxicity and estrogenicity were perceived with increased radiation dose mainly in aqueous solution signifying the probable utilization of gamma radiation on food to lessen the toxicity in food products. Change in the shelf-life of pasta upon using gamma radiation at different doses within a period of 90 days (Cassares *et al.,* 2020) was examined. Along with reduced water absorption, irradiated pasta showed a significant reduction of the microbial count at 13kGy dose at 25°C without affecting any other sensory properties. A study (Kim *et al.,* 2020) applied a 10kGy dose of gamma radiation to evaluate the effect upon the properties of an uncooked Korean meal consisting of several plants and animal sources, named Saengshik. Although chlorophyll and total carotenoid levels were found to be lesser at high dose, improved free radical scavenging activity with higher gamma radiation dose resulted in enhanced total phenolic content and antioxidant activity without altering any other properties. 1 kGy gamma radiation was applied upon bread-making wheat flour available in Mexican market (Agúndez-Arvizu *et al.,* 2006).

Still, most of the people are afraid of consuming irradiated products due to same underlying situation, the communication gap between researchers and consumers. Hence, more studies are required to encourage the use of irradiation technique in food industry and distribute the knowledge among general population.

1.3.1. Gamma radiation

In today's life, increasing demand for cost-effective nutritious food formulated from organic ingredients without any chemical preservatives is an indication of modernization and growing health awareness of society. Besides health concerns, enhanced shelf-life is another challenge nowadays and irradiation technology is found to be efficient as well as effective to face this challenge. The use of irradiation in the food industry can be a potent alternative to process postharvest mass without utilizing any chemical substances (Calado *et al.,* 2020). Food irradiation can enhance the storage stability, nutrient availability of the food which does not affect the sensory scores (FDA, 2016; Indiarto and Qonit, 2020). The technology of irradiation in the food domain besides preserving foods, can also be used for sterilization (Handayani and Permawati, 2017).

1.3.2. Role of gamma radiation in the reduction of microbial load and nutrient spoilage

Radiation is generally categorized as ionized and non-ionized. High dose photons viz., alpha particles, protons, and neurons generally are the primary source of ionizing radiation consists of energy more than kilo-electron volts. The electromagnetic emissions or high energy particles from ionizing radiation can disrupt chemical bonds present in biomolecules (Daly, 2009; Trudeau *et al.,* 2012).

Ionization disrupts the phosphodiester bond as well as the hydrogen bond on the DNA strand of a microbe destroying the pathogen. However, some microbes are possessing the ability to resist radiation and recover the effect. D10 is the amount of dose that can kill microbial pathogens by 10 fold (Calado *et al.,* 2020). Pathogens showing a higher value of D10 are highly resistant to irradiation. This resistance might occur due to different factors such as microbial DNA size and its composition, oxygen, water content, temperature, post-radiation circumference. Thus other effective technologies such as fogging or frosting along with gamma radiation can diminish the resistance properties of those microbes properly. Application of lower temperature ceases the enzymatic activity and damages the protoplasm of colloidal systems (Trudeau *et al.,* 2012).

It has been found that besides being health-friendly, the irradiation process is also cost-effective in comparison to other decontamination processes. Hot water immersion and steam treatment almost cost around 250 US$/Ton whereas freezing and atmosphere control make the expense bar touch 40-600 US$/Ton. On the other hand, irradiation treatment can be done by spending 25-55 US$/Ton (Handayani and Permawati, 2017).

The sources of gamma radiation that are permitted to use upon food products are the radioisotope Cobalt-60 and Caesium-137 (Belyakov *et al.,* 2018). Low-level energy radiation is being applied to food materials. Irradiation is generally emitted energy in the form of waves or moving particles, sufficient to remove electrons from atoms or molecules. Application of radiation in food sometimes can result in low-level fat oxidation leading to the production of undesirable compounds that affect the sensory profile of foods and shelf-life along with polymerization, decarboxylation, and dehydration (Mustapha *et al.,* 2014; Damodaran *et al.,* 2007; Najafabadi *et al.,* 2017; Ocloo *et al.,* 2014; Shi *et al.,* 2015). But the accurate amount of applied dose of radiation can enhance the nutritional status of food along with improved shelf-life. The amount of dose required to irradiate the food product depends on certain parameters viz., smoothness, geometry, the density of the product (Indiarto and Qonit, 2020). According to Food and Agriculture Organization (FAO), International Atomic Energy Agency (IAEA), World Health Organization (WHO), and

Codex Alimentarius irradiation are health-friendly and energy-efficient (Handayani and Permawati, 2017; CAC, 2003b).

Food/ agricultural products	Level of dosage applied	Outcome of the study	Reference
Banana	Three doses were applied- 0.30 kGy, 0.40 kGy, 0.50 kGy and stored at room temperature.	Improved storage stability till 21-26 days where accepted dose was 0.30 kGy. Negligible changes found out in the nutrients with minimal loss of ascorbic acid.	(Zaman *et al.*, 2007)
Rice bran	Electron beam irradiation (EBI) pretreatment at the range of 0-300 kGy.	Increased cellulose and decreased hemicellulose. Improved enzymatic hydrolysis yield of fibre obtained from rice bran	(Li *et al.*, 2020)
Wheat flour (Whole) and chapattis made from the flour	Gamma radiation	Increased shelf life up to 6 months after exposure to 0.25-1.00 kGy	(Marathe *et al.*, 2002)
Rice bran	Infrared radiation heat treatment	Lower lipase and peroxide activity. Increased shelf-life to 71.6 and 25.8 weeks. Suppressed microbial growth.	(He *et al.*, 2020)
Pasta	Gamma radiation	Effectively reduced microbial growth at 13 kGy. No significant change in nutrients. Decreased water absorption. No change in sensory properties even after 90 days.	(Cassares *et al.*, 2020)

Table 1. 6: Applications of radiation on plant-based food products

1.3.3. Effect of gamma radiation on food products

The use of 3kGy of gamma radiation can decrease the microbial population of *Listeria monocytogenes* and *Vibrio parahaemolyticus* induced in smoked salmon without alteration of its sensory score. Based upon the action to be accomplished permitted dose of radiation is determined. 1 kGy is enough to cease germination and delay in the ripening. For purpose of pathogen destruction medium range of radiation is needed that is almost 1-10 kGy. However, more than 10kGy of a high dose is applied for the process of sterilization and decontamination. Though dose ranges are mentioned in previous studies, they cannot be used as a defined measure because radiation doses might differ depending upon the surroundings. The utilization of gamma radiation upon food products also eradicates mycotoxins (Calado *et al.,* 2020). In a study (Calado *et al.,* 2020), the effect of gamma radiation on Zearalenone was investigated to determine the cytotoxicity as well as the estrogenicity of Zearalenone after the application of gamma radiation (0.4 to 8.6 kGy). A significant increase in the degradation of Zearalenone was observed along with increased moisture content. Reduced cytotoxicity and estrogenicity were detected with increased radiation dose mainly in aqueous solution signifying the probable utilization of gamma radiation on food to lessen the toxicity in food products. The shelf-life of pasta was enhanced by gamma radiation at different doses viz., 5,10, and 13 kGy at different temperature (7°, 15°, 25°C) within a period of 90 days (Cassares *et al.,* 2020). Though reduced water absorption of pasta was noticed, irradiated pasta showed a significant reduction of the microbial count at 13kGy dose at 25°C without affecting any other sensory properties. Despite the permitted dose of 5kGy of gamma-ray for irradiation for cereal ingredients in Korea, decontamination effects are not satisfied often. A study (Kim *et al.,* 2020) applied a 10kGy dose of gamma radiation to evaluate the effect upon the properties of an uncooked Korean meal consisting of several plants and animal sources, named Saengshik. Although chlorophyll and total carotenoid levels were found to be lesser at high dose, improved free radical scavenging activity with higher gamma radiation dose resulted in enhanced total phenolic content and antioxidant activity without altering any other properties. 1 kGy gamma radiation was applied upon commercial Mexican bread-making wheat flour by utilizing 60C Gamma beam 651 PT irradiator facility (Agúndez-Arvizu *et al.,* 2006). The study revealed decreased microbial load viz., total aerobic, yeast, and mold counts were less by 96%, 25%, and 75% without distressing any other properties significantly. Astronauts in the National Aeronautics and Space Administration (NASA) space shuttle program consumed foods which were exposed to gamma radiation for sterilization purpose. Radiation technology already has been applied for the sterilization of ready-to-eat space food named 'Bibimbap' (Singh, 2020). For immune-compromised individuals, irradiated food is found to be appropriate. Hence, instant foods for the patients undertaking chemotherapy treatment, military personnel, hikers are also being sterilized using radiation technology (Singh, 2020).

Among the plant origins, the food professionals have recognized and increasingly appreciated the food value of mushrooms, because of the low calorific value and very high contents of protein (20-40% on dry weight basis), vitamins and minerals. Mushroom protein can serve as supplementary food contributing proteins in developing countries where the population mainly depends on cereal-based foods. Mushrooms have low carbohydrate content, no cholesterol and are almost fat free. Fat content available in edible mushroom is 0.2g/100g (CHATTERJEE *et al.,* 2021). It has been reported that daily intake of 100-200g (dry weight) of mushroom can provide nutritional balance in a normal human being (CHATTERJEE *et al.,* 2021). These plant based products are prone to microbial contaminations. Fungal contamination leads to production of harmful substances such as mycotoxins. Deterioration of wheat bread due to fungus (Dalié *et al.,* 2010) is mainly caused by Penicillium species (Legan and Voysey, 1991). The irradiation process is another preferred process by several researchers to minimize post-harvest losses (Gould 1996). In contrast, application of ionizing radiation such as gamma radiation at a low dose was found to be suitable for food preservation (Jan *et al.,* 2020).

Almost 60 countries are utilizing irradiation on food at present with approved doses and food class with a statement of the purpose of using radiation or certifiable benefit on the appropriate label viz., Brazil, Singapore, USA, Canada, Australia (Handayani and Permawati, 2017). In India (Table 1.10), the first food items that got the approval to use radiation and be available for domestic marketing were potatoes, onions, and spices (Health authorities of India in 1994). In 1998 and 2001 other products got the approval. (Singh, 2020).

Class	**Food products to be irradiated**	**Applied Treatment**	**Applied dose (kGy)**
Class 1	Bulbs, stem, root tubers, rhizomes	Sprouting inhibition	0.02 – 0.2
Class 2	Fresh fruits and vegetables (other than Class 1)	Delayed ripening	0.2 – 1.0
Insect disinfestation	0.2 – 1.0		
Shelf life extension	1.0 – 2.5		
Quarantine application	0.1 – 1.0		
Class 3	Cereals & their milled products, pulses & their milled products, nuts, oil seeds, dried fruits and their products	Insect disinfection	0.25 – 1.0
Diminish of microbial count	1.5 – 5.0		
Class 4	Fish, aquaculture, seafood and their products (fresh or frozen) and crustaceans	Eradication of pathogenic microbes	1.0 – 7.0
Enhanced Shelf life	1.0 – 3.0		
Control of human parasites	0.3 – 2.0		
Class 5	Meat and meat products including poultry (fresh and frozen) and eggs	Elimination of pathogenic microorganisms	1.0 – 7.0
Shelf life extension	1.0 – 3.0		

Control of human parasites	0.3 – 2.0		
Class 6	Dry vegetables, seasonings, spices, condiments, dry herbs and their products, tea, coffee, cocoa and plant products	Microbial decontamination	6.0 – 14.0
Insect disinfestation	0.3 – 1.0		
Class 7	Dried foods of animal origin and their products	Insect disinfestation	0.3 – 1.0
Control of moulds	1.0 – 3.0		
Elimination of pathogenic microorganisms	2.0 – 7.0		
Class 8	Ethnic foods, military rations, space foods, ready to-eat, ready-to-cook, minimally processed foods	Quarantine application	0.25 – 1.0
Lessening of microbial load	2.0 – 10.0		
Sterilization	5.0 – 25.0		

Table 1. 7: Classes of food products allowed for radiation processing by Govt. of India and their absorbed dose limits (*Official Gazette of India on August 23, 2016*)

In case of the storage stability of product which is a major point to consider (Karlsson *et al.,* 2019), in comparison with natural milk, adulterated milk shows longer shelf life due to presence of added urea, detergent, vegetable oil etc. The pH of Natural milk is almost neutral or slightly acidic. Presence of urea in milk change pH of the same and alters it to basic. Elevated urea concentration prevents aggregation and precipitation of protein matter present in milk. This leads to stabilization of milk protein resulting in longer shelf life (Williams, 2002; Crowley *et al.,* 2014). This is one of the reasons the practice of production of synthetic milk in market is increasing day by day. Addition of the adulterants cause fatal health conditions (Monika and Gupta, 2008). As a replacement for available methods to determine the adulteration in food products, the concept of studying the interaction between radiation with materials to detect presence of added elements is attracting the scientific community (Udagani and Ramesh, 2014). Based upon the obtained attenuation coefficient of product, presence of adulteration can be detected. The attenuation coefficient is basically the measurement by which penetrated incident energy beam through a material can be studied. Due to presence of definite elements, exposed gamma radiation either get absorbed in the sample or scattered in certain manner and escape. The occurrence of this phenomenon of gamma radiation is different for different elements. Therefore, comparative study of obtained attenuation co-efficient from synthetic and natural products can be helpful further to detect the adulteration.

Besides food formulation, it is also crucial to maintain the quality of the product to avoid the adverse effect of contaminants or present adulterants upon health. Although several health drinks, dairy based drinks and beverages are available in market, presence of added foreign elements (adulterants) in these drinks make them inappropriate for health. For example, India is considered to be one of the highest milk production countries (annual production of around 127 million tons) worldwide according to NDDB (National Dairy Development Board) (2013) (Mudgil & Barak, 2013). However, to meet the consumer need and peer pressure along with maintenance of economical profit, there occurs an emergence of production of synthetic milk. Addition of adulteration to natural milk although makes the milk visually seems perfect, the manipulation in the nutrient contents of the produced milk creates serious concern for health. Natural milk is obtained from lacteal secretion by complete milking which contains definite percentages of fat, protein, solids. Hence, several tests viz., determination of fat and solids, freezing point, bacterial count etc. are available to detect the added chemicals like vegetable oil, urea, detergent etc. in the milk (Mudgil & Barak, 2013). But the determination procedures are expensive and time consuming (Mudgil & Barak, 2013). According to Indian Council of Medical Research (ICMR) report, addition of such foreign elements in milk can show hazardous effect on human health resulting in impairment of biological systems over the time. The most common difference in the properties of synthetic and natural milk is that on rubbing on the palm, synthetic milk produces foam. pH of the synthetic milk is also highly alkaline (pH 10-11) in comparison with natural milk (pH 6.6-6.8) which is almost neutral in nature. On heating in case of synthetic milk, the colour of milk turns to pale yellow after sometimes. Whereas, under the similar conditions the colour of natural milk remains the same (Bansal & Bansal, 1997). Presence of different adulterants in the synthetic milk changes the primary composition of milk that adversely affects the health. Component like urea is source of nitrogen which indirectly increase the protein content of milk. Urea is generally added to milk sample to increase the milk solid not fat (SNF) content for the thick and concentrated texture. Due consumption of such milk over time results increased toxicity in body (Mudgil & Barak, 2013). According to the Expert committees from World Health Organization (WHO) and Food and Drug Administration (FDA) toxicity of adulterants, crystal formation due to added elements can lead to blockage of renal tubes resulting in failure in the functioning of kidney (WHO, 2009a; WHO,2009b; US FDA).

Based upon the reviewed literature it can be said that the irradiation process is safe at a specific dosage and has already been used in the case of formulated food products of plant origin (Cassares *et al.,* 2020). Very few studies are available indicating usage of radiation upon foods made from by-products (He *et al.,* 2020). According to this literature review, irradiation process such as gamma radiation can be a way out to get higher shelf life food products developed from these by-products with minimal nutrient losses.

1.3.4. Impression of consumers on gamma irradiated products and the acceptance rate

The food irradiation besides being efficient and cost-effective technology to eliminate food contamination, also prolong storage stability of foods without affecting significantly their sensory attributes and nutrient composition (Maherani *et al.,* 2016). Regulatory agencies as well as national and international organizations also declared irradiated food safe (Junqueira - Goncalves *et al.,* 2011).

Sensory parameters of the irradiated products were carried out in several studies to understand the sensory attributes, acceptability and descriptive textural properties of the products. Sensory analysis of Cobalt 60 source (SLL 515, Hungary) irradiated steamed mushrooms was carried out using a questionnaire according to 9-point Hedonic scale (Kortei *et al.,* 2020). Although gamma radiation did not alter the sensory attributes, during consumer acceptability evaluation, non-irradiated mushrooms were preferred mostly due to wrong perceptiveness regarding influence of irradiation technology on food properties (Maherani *et al.,* 2016).

Another study was conducted to explore willingness of consumers towards irradiated foods through an online survey. According to the obtained data also depicted the same observation. Although, sensory properties of the foods are not affected significantly by the exposed dose during the food irradiation processing, the willing of consumers to accept such foods got affected due to their perceived risk to health (Galati *et al.,* 2019).

The gap between the consumers and the proper scientific knowledge of food irradiation technology can be the probable reason of aversion by the consumers. Thus it is necessary to enlighten people about the food safety issues and the solution to such situations using this novel technology with benefits.

1.4. Gap in the study

According to the available survey data (McKenzie and Williams, 2015), a huge amount of food gets wasted. The health benefits and food values of the cereals, legumes, vegetables and fruits are already known, but the by-products like bran, husk (i.e., choker, bhoosa, churi), peel are either discarded or used as animal food. These by-products, also known as agricultural by-products or agro-industrial wastes, are rich in fibre, minerals, bioactive compounds like antioxidants, phenols and possess less carbohydrate and fat (Zeng & Lazarova, 2014). These are either generated from industrial processing of crops, fruits, vegetables or during the post-harvest processing of the same.

According to the researchers, these discarded by-products contain more health beneficial factors (Niño-Medina *et al.,* 2019) and yet are not much being used as food sources for human. Most of them are either discarded in open environment and burnt, leading to environmental pollution or use as animal food (Girotto *et al.,* 2015). A small fraction of them are used in food industries. Survey data also mentioned that due to increasing population rate, without any strategic intervention there will be food shortage by 2050 (McKenzie and Williams, 2015). Besides declination of food wastage, conservation of various food sources is crucial to maintain food and nutrition security. Thus, along with various plant sources, researchers are also keen to show interest to utilize the nutrient rich by-products like husk, bran, peels as potential novel food ingredient (Zeng & Lazarova, 2014). Our ancestors did not use to refine or process the grains much. Thus, their foods were used to be enriched with these nutritious brans and husks. While, food professionals already started to study the food value of these plant based by-products which are part of agro-industrial wastes, more study is required in this emerging area of food science. Although cereal brans like rice bran, wheat bran, broken rice are gaining popularity among consumers and food industries, legume husks such as chickpea husk, moong bean husk are yet to reach that mark (Niño-Medina *et al.,* 2019). They are generally used in chemical industries and for animal feed in spite of rich nutrient composition, especially dietary fibre.

Beside this scenario, due to the busy lifestyle and competitive work schedule, sometime health and diet pattern gets compromised. Also, the lack of awareness about impact of nutritious diet intake upon wellbeing and daily activities leads to poor health condition resulting in fatal diseased conditions. A communication gap between food experts and common people must explain this casualty. However, nowadays people are becoming concerned about their health. Moreover, sudden emergence of the pandemic due to COVID-19 made people realize that, good health is the most important aspect of a hale and hearty lifestyle. They are trying to maintain their health by incorporating nutrient rich foods in diet and getting enlightened about the role of nutrition to improve biological functions of body. Thus, to compensate with the hectic lifestyle, ready-to-cook/eat or instant food mix with maximum availability of nutrients are in demand. Based upon novel emerging food science and technologies, food professionals are using underutilized medicinal plant sources by remodelling traditional food practices to fulfil this demand.

Regarding the nutri-dense instant food formulation, among various sources plant based foods are gaining more popularity due to their therapeutic advantages and lesser health-deteriorating factors (Helkar *et al.,* 2016). Although plant sources contain certain amount of antinutrient, various culinary treatments viz., soaking, blanching, microwave heating, fermentation, germination are being implemented to minimize the adverse effect and activity of those compounds/factors (Patterson *et al.,* 2017).

Another concern for health benefits is use of chemical preservatives to enhance the shelf life of products leading to gradual deterioration of health. Use of fumigants such as ethylene dibromide (EDB) for agricultural products became debatable due to health concerns and side effects of some of those chemicals are found to be carcinogenic. In contrast, application of ionizing radiation such as gamma radiation at a low dose was found to be suitable for food preservation without causing any health hazard (Zaman *et al.,* 2007).

1.5. Objective of study carried out in present thesis

Keeping all these scenarios in mind, in the current study, characterization of milling by-products of chickpea (chickpea husk) and moong bean (moong bean husk) were done along with some other agricultural by-products, also known as plant-based by-products (rice bran, broken rice, wheat bran, orange peel, and banana peel) as novel ingredients to find out their potential uses in food formulation and health benefits. Valorisation of milling by-products can improve the bioavailability of protein, lipids, starch, dietary fibres along with micronutrients, and other bioactive molecules (Girotto *et al.,* 2015).

Following are the main objective of the study:

i. To determine the physicochemical properties and nutritional composition of by-products.
ii. To develop value added products incorporating by-products of cereals and pulses and to study their sensory evaluation and consumer acceptability.
iii. To study nutrient composition and shelf life of the most acceptable value added products
iv. To popularize the acceptable product and transfer the technology regarding their preparation and utilization.

1.6. Scope of the study

Study of the agricultural by-products gives the information for both the therapeutic properties of the obtained by-products and for future data reference, to formulate the value-added products using those by-products followed by determination of sensory acceptance and enhancement of the shelf life of the products.

Development of various novel products using by-products is useful to study the potential role of legume by-products as well as other agricultural by-products as innovative ingredients for food formulation. Determination of nutrient availability and sensory acceptance of the value-added products due to various processing techniques can depict the scope of incorporation of such by-products in daily diet. Study of food irradiation to enhance the shelf life of the products can be helpful to retain nutritional and consumption quality of the food products instead of using chemical preservatives. Analyzation of food value of the agricultural by-products along with their processing and preservation in the present study can be beneficial to combat food shortage and malnutrition in near future.

1.7. Organization of thesis

Organization of thesis is as follows:

In chapter 2, procurement and processing of raw materials followed by methodology for nutrient estimation has been discussed. Standardised methods of AOAC to analyse physico-chemical properties, proximate composition, Total sugar, mineral availability, antioxidant activity, antinutrient have been elaborated. We shall discuss the experimental technique to study the shelf life (peroxide value, free fatty acid value), sensory acceptance (using 9-points Hedonic scale) of the developed value-added products using the raw materials which are the milling by-products (agricultural by-products) of chickpea, moong bean, rice and wheat. We shall discuss food irradiation using gamma sources i.e., ^{137}Cs and ^{60}Co to enhance the shelf life of perishable products along with use of GM counter and scintillation detector to detect counts. Also we shall discuss about the popularization of the processing of the raw materials and developed products.

In chapter 3, we shall study in detail about the formulation of milling by-product-based fermented products like *idli* using instant mix and *paneer* (Bran *paneer*). We shall estimate the percentage composition of various by-products used to formulate these value added products. We will compare the results of nutrient composition, shelf life at different storage conditions, microbial load of the formulated fermented products- Instant Mix (IM) and Bran *paneer* (BP). We will also study the effect of food irradiation using gamma sources to enhance the shelf life of Bran *paneer*.

In chapter 4, we shall study in detail about the formulation of bakery products like cookies and bread using milling by-products and other ingredients. We shall estimate the percentage composition of various by-products used to formulate these value added products. We will compare the results of nutrient composition, shelf life at different storage conditions, microbial load of the formulated baked products- Multibran cookies, Mushroom cookies, Mushroom bread and Bran Bread with wheat flour product. We will also study the effect of food irradiation using gamma sources to enhance the shelf life of these products.

In chapter 5, we shall study in detail about the formulation of agricultural by-product-based snack products like Gram Pak (GP), *papad* (PD), and Bran Bar (BB). We shall estimate the percentage composition of various by-products used to formulate these value added products. We will compare the results of nutrient composition, shelf life at different storage conditions, microbial load of these formulated products. We will also study the effect of food irradiation using gamma sources to enhance the shelf life of Gram Pak.

In chapter 6, we shall study in detail about the formulation of agricultural by-product-based health drink and beverage like Health drink powder (HDP) and Detox-tea substitute (DTS). We shall estimate the percentage composition of various by-products used to formulate these value added products. We will compare the results of nutrient composition, shelf life at different storage conditions, microbial load of the formulated products. We also study the role of gamma radiation to detect adulteration in liquid sample like milk. We shall discuss about the pattern of milk protein coagulation based upon present adulterants and gamma radiation.

In chapter 7, results have been summarized along with an outlook of the work.