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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(7): 727-735

www.thepharmajournal.com
Received: 23-04-2023
Accepted: 28-05-2023

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Shelf-life extension of wheat flour by irradiation technique

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DOI: https://doi.org/10.22271/tpi.2023.v12.i7Si.21408

Abstract
Irradiation is the process of exposing the food to some dose of radiation to extend the shelf life of the food. The present study was done on shelf-life extension of wheat four by gamma radiation. Gamma rays are used for food processing, whose light source is obtained from a 60 Co radionuclide source. Irradiation properties of gamma rays have adverse effects on nutritional properties of whole wheat flour with dose less than 5 kGy. The physiochemical properties and the nutritional properties of wheat has been analysed. The moisture content of untreated flours (8.69%), treated flour (7.73%) and microbial activity of untreated flour of the whole wheat flour has been reduced by the dose of radiation. However, the physiochemical parameters of wheat flour such as, ash untreated (1.98%) treated (1.93%), fat untreated (1.75%) treated (1.74%), protein untreated (16%) treated (9.27%), fibre untreated (2.06%) treated (2.10%), has been analysed when introduced to radiation. The techno-functional parameters of treated and untreated wheat flour such as, water absorption capacity (WAC), water absorption index (WAI), bulk density has no effect while introduced to radiation. The effect of irradiation on food has been studied that at high dose of radiation, there is more liable to flavour change.

Keywords: Irradiation, gamma rays, wheat flour, bioactive compounds, shelf life

Introduction

Cereals are very important crops from the economic, agronomic, and consumer point of view. Among cereals, rice and wheat are in high demand and are cultivated on a large scale. Wheat is one of the most important staple foods around the world. The presence of nutrients such as starch, protein, minerals, vitamins, and lipids makes wheat flour highly promotable as a balanced diet (Xiao *et al*., 2020) [1]. Wheat and its by-products are utilized in a wide range, wheat is mainly used as raw material in bakery products, beverage industry, cosmetics, ethanol production, and also as animal feed. Whole wheat flour consumption protects humans against diseases such as constipation, appendicitis, non-alcoholic fatty liver diseases, and obesity (Kumar *et al*., 2011) [22]. Wheat is one of the world most commonly consumed cereal grain. It comes from a type of grass (Triticum) that is grown in countless varieties worldwide, white and whole-wheat flour are the key ingredients in baked goods, such as bread. Other wheat-based foods include pasta, noodles, semolina, bulgur, and couscous (Ahmad *et al*., 2014). Wheat is mainly composed of carbohydrates, but also has a moderate amount of protein. (Calories-340, Protein-13.2gm, carbohydrates-72 gm, fiber-10.7 gm, fat-2.5 gm). starch is the predominant carbohydrate in the plant kingdom, accounting for over 90% of the total carbohydrate content in wheat. wheat is mainly composed of carbohydrates, fibre content in of whole wheat grain is 12-15% of the dry weight. As they are concentrated in the bran, fibre is removed during the milling process and largely absent from refined flour. The main fibre in wheat bran is arabinoxylan (70%), which is a type of hemicellulose. The rest is mostly made up of cellulose. Vitamins and minerals, as with most cereals grains (Erkmen *et al*., 2016) [23].

The amount of minerals depends on the soil in which its grown. Selenium this trace element has various essential functions in our body. Manganese is found in high amounts in whole grains, manganese may be poorly absorbed from whole wheat due to its phytic acid content. Phosphorus this dietary mineral plays an essential role in the maintenance and growth of body tissues (Kirwan *et al*., 2013) [24]. The main concern of agriculture is pre and post-harvest losses, the significant losses are caused by inadequate storage conditions as well as decisions made at earlier stages of the supply chain, including transportation, storage, and processing, which predispose products to a shorter shelf life. The true extent of post-harvest losses is the subject of some dispute as they are difficult to measure accurately. According to the world food programme, 40% is common.

In Africa, post-harvest losses of maize from harvest sales are believed to amount to around 10-20%, Approximately 40% of these losses occur during storage at the farm and market, 30% during processing (drying, threshing, and winnowing), 20% in transport from the field to the home stand, and the remaining 10% during transport to market. As there is high chances of losses during storage (i.e 40%) of cereals. extending the shelf life of food products is one of the main objectives of food producers, especially about the perishable foods. One of the most important methods for extending of shelf life is by irradiation treatment, which will ultimately improve food health. The awareness in consumers about the health benefits associated with the consumption of whole grain foods has increased their demand to a large extent. Whole wheat flour is a rich source of antioxidants which play an important role in preventing cancer and cardiovascular diseases. However, the shelf life of wheat grains is limited to 6-8 weeks owing to insect infestation even in sealed pouches. The conventional methods of fumigation are not possible for sealed pouches as the fumigants cannot penetrate the same. Therefore, gamma irradiation provides an alternative method for preventing insect infestation as well as food spoilage and food-borne illness (Salem *et al*., 2016) [25]. The main concern of agriculture is pre and post-harvest losses, the significant losses are caused by inadequate storage conditions as well as decisions made at earlier stages of the supply chain, including transportation, storage, and processing, which predispose products to a shorter shelf life. The true extent of post-harvest losses is the subject of some dispute as they are difficult to measure accurately. Early experiments showed that ionizing radiation kills bacteria. Promising and scientifically interesting as they were, these early efforts did not lead to the use of ionizing radiation by the food industry. At the turn of the century and for many years thereafter, there was no cost-effective way of obtaining radiation sources in the quantity required for industrial application. The X-ray generators of the day were very inefficient in converting electric power to X-rays, and the naturally occurring radioactive materials, such as radium, were too scarce to provide gamma rays, or other forms of radiation, in sufficient quantities for food processing. To overcome these losses modern techniques like irradiation treatments are used to increase the shelf of the product. Food irradiation is one of the modern, secure, and efficient ways for its preservation, which is practised in many countries around the world (Bason *et al*., 2017) [5].

Food irradiation has an advantage over traditional methods as it is likely to maintain food quality for longer periods. Food irradiation is a very mild treatment, as absorption of radiation dose of 1 KGY is able to increase the temperature of the product by 0.36 °C. This indicates the minimum nutritional losses in irradiation than heating, drying and cooking. Along with that irradiated foods do not initiate the production of heterocyclic ring compounds and carcinogenic aromatics as it is found in thermal processing of food at high temperatures (Bornare *et al*., 2018) [26]. Irradiation techniques like gamma, electron beam, and X-ray are used for food irradiation. Among them, gamma irradiation is more popular for food processing and food irradiation because of its high penetration power and efficiency to eliminate contamination. Also, electron beam irradiation is not preferred over gamma irradiation because electron beam irradiation induces the formation of free radicals such as hydroxyl radicals and peroxyl radicals (Brasoveanu *et al*., 2013) [27]. Food irradiation, (the application of ionizing radiation to food) is a technology that improves the safety and extends the shelf life of foods by reducing or eliminating microorganisms and insects. Like pasteurizing milk and canning fruits and vegetables, irradiation can make food safer for the consumer. The Food and Drug Administration (FDA) is responsible for regulating the sources of radiation that are used to irradiate food. The FDA approves a source of radiation for use on foods only after it has determined that irradiating the food is safe (Kulsum *et al*., 2020) [2]. Gamma rays are produced from radioisotopes cobalt-60 and cesium-137, cobalt-60 is produced in a nuclear reactor via neutron bombardment of highly refined cobalt-59 pellets, while cesium-137 is produced as a result of uranium fission, both cobalt-60 and cesium-137 emit highly penetrating gamma rays. Radiated food prevents of food borne illness-to effectively eliminate organisms that cause food-borne illness, such as salmonella and Escherichia coli. Prevention to destroy or inactive organisms that cause spoilage and decomposition and extend the shelf life of foods. Control of insects-to destroy insects in or on tropical fruits imported into the United States. Irradiation also decreases the need for other pest-control practices that may harm the fruit. Delay of sprouting and ripening to inhibit sprouting and delay ripening of fruit to increase longevity (Haripriya *et al*., 2010) [3].

The gamma irradiation studies reported changes in wheat flour protein if irradiated above 10 KGY dose. Modification in wheat protein leads to a decline in dough property, which affects the quality and life of bakery products like bread and buns. The effect of gamma-ray was reported on a few properties of wheat flour at particular doses like 0.5, 1, 2.5, 5, and 10 kGy. Satin *et al*., (2002) [4] studied the effect of gamma irradiation on the physicochemical properties of whole wheat flour samples at 2.5 and 5 kGy doses. Their results revealed a significant decrease in water absorption, oil absorption, swelling power and emulsion capacity whereas, water solubility index, emulsion stability, foaming capacity and stability were found to increase upon irradiation. Decrease in pasting properties and intensities of few bonds in the structural analysis were reported with irradiation. On the contrary, no changes in the proximate composition, bulk density and FTIR spectra pattern were reported with dosage. Also, a significant increase in amylose content, swelling, solubility, syneresis and freeze-thaw stability, water and absorption capacity of the flour with dosage was reported by (Bashir *et al*., 2017) [28]. The research group of Khan *et al*., (2018) [7] reported no change in the chemical composition of wheat flour and increasing dough water absorption in wheat flour irradiated at 5 kGy. The literature reported so far gives mixed results on the effects of gamma irradiation on proximate composition, bulk density, functional properties and FTIR spectra of wheat flour.

Irradiation

Satin *et al*. (2002) [4] observed that the food irradiation is a process exposing food to ionising radiations such as gamma rays emitted from the radioisotopes 60 Co and 137Cs, or, high energy electrons and X-rays produced by machine sources. Depending on the absorbed radiation dose, various effects can be achieved resulting in reduced storage losses, extended shelf life and/or improved microbiological and parasitological safety of foods. However, hindering factors in the way of commercial implementation of the food irradiation process are politics and consumer advocacy. A similar situation occurred with the heat pasteurisation of milk in the past.

Moy *et al*. (2002) [29] stated that the potential application of ionising radiation in food processing is based mainly on the fact that ionising radiations damage very effectively the DNA so that living cells become inactivated, therefore microorganisms, insect gametes, and plant meristems are prevented from reproducing, resulting in various preservative effects as a function of the absorbed radiation dose. At the same time, radiation-induced other chemical changes in food are minimal. According to the Codex General Standard for Irradiated Foods CAC. (2003), it has been reported that ionising radiations foreseen for food processing are limited to high energy photons (Gamma rays of radionuclide's 60 Co and, to a much smaller extent, 137 Cs, or, X-rays from machine sources with energies up to 5 MeV, or accelerated electrons with energies up to 10 MeV. In the USA, the Food and Drug Administration amended recently the food additive regulations by establishing a new maximum permitted energy level of X-rays for treating food of 7.5 MeV provided that the X-rays are generated from machine sources that use tantalum or gold as the target material. High-energy electron beams are produced by electron-accelerating machines. X-ray production starts with high-energy electrons: X-ray machines convert electron energy to electromagnetic X-rays called "Bremsstrahlung" These types of radiation are chosen because they produce the desired food preservative effects, they do not induce radioactivity in foods or packaging materials, they are available in quantities and at costs that allow commercial use of the irradiation process.

Bradley *et al*. (2015) [30] examined differences in radiation sensitivities among the microorganisms are related to differences in their chemical and physical structure, and in their ability to recover from radiation injury. The amount of radiation energy required to control microorganisms in food, therefore, varies according to the resistance of the particular species and according to the number of organisms present. Besides such inherent abilities, several factors such as the composition of the medium, the moisture content, the temperature during irradiation, the presence or absence of oxygen, the fresh or frozen state influence radiation resistance, particularly in the case of vegetative cells. Similar to heat resistance, the radiation response in microbial populations can be expressed by the decimal reduction dose. Summarizing data from a large number of references, presents typical radiation resistances of a number of bacteria in non-frozen foods. The radiation sensitivity of many moulds is of the same order of magnitude as that of vegetative bacteria. However, fungi with melanised hyphae have a radiation resistance comparable to that of bacterial spores Yeasts are as resistant as the more resistant bacteria. Viruses are highly radiation resistant.

Basson *et al*. (2017) [5] observed early experiments that showed that ionizing radiation deteriorates bacteria. Promising and scientifically interesting as they were, these early efforts did not lead to the use of ionizing radiation by the food industry. At the turn of the century and for many years thereafter, there was no cost-effective way of obtaining radiation sources in the quantity required for industrial application. The X-ray generators of the day were very inefficient in converting electric power to X-rays, and the naturally occurring radioactive materials, such as radium, were too scarce to provide gamma rays, or other forms of radiation, in sufficient quantities for food processing.

Properties of gamma rays

Khan *et al*. (2018) [7] studied irradiation food preservation uses high energy, known as ionizing radiation. It is because the material in its path can be ionized. When irradiation sources such as X-rays, gamma rays, and electron beams touch the material, these foods, and components will be excited, ionized, and altered. An excitation is an event where living cells become sensitive to external conditions. Ionization is the process by which macromolecules are broken into free radicals. Changes in living cells components will inhibit DNA synthesis, disrupting microbial cell division, and biological effects. This effect inhibits microbial growth in food.

Rawat *et al*. (2015) [8] reviewed gamma rays are used for food processing, whose light source is obtained from a 60 Co radionuclide source. This type of radiation is essentially monoenergetic. Using analytical methods such as the kernel point or the Monte Carlo method, it is straightforward to calculate the spread of irradiation doses in food products. The resulting dose depth distribution will resemble an exponential curve. Irradiation from two sides, obtained by rotating the processing load, is often used to enhance dose uniformity in system loads. Its applications on food were widely used.

Kim *et al*. (2004) [31] reported gamma rays, X-rays, visible light, and UV are all of electromagnetic (EM) radiation. EM radiation differs in frequency and hence in energy. Gamma rays are the most energetic form of such electromagnetic radiation, having the energy level from around 10 keV to several hundred keV volts, and therefore they are more penetrating than other radiation such as alpha and beta rays. Gamma rays belong to ionizing radiation and interact to atoms or molecules to produce free radicals in cells. These radicals can damage or modify important components of plant cells and have been reported to affect differentially the morphology, anatomy, biochemistry, and physiology of plants depending on the irradiation level. These effects include changes in the plant cellular structure and metabolism, e.g., dilation of thylakoid membranes, alteration in photosynthesis, modulation of the ant oxidative system, and accumulation of phenolic compounds.

Barbara *et al*. (2002) [9] studied physiological symptoms in a large range of plants exposed to gamma rays have been described by many researchers. The symptoms frequently observed in the low- or high-dose-irradiated plants are enhancement or inhibition of germination, seedling growth, and other biological responses. The growth of Arabidopsis seedlings exposed to low dose gamma rays (1 or 2 kGy) was slightly. The relationship between growth of irradiated plants and dose of gamma irradiation has been manifested by investigating the morphological changes and seedling growth of the irradiated plants. No significant morphological aberrations were observed in the phenotype of the plants irradiated with relatively low doses (1–5 kGy) of gamma rays, while a high-dose (50 kGy) irradiation inhibited seedling growth remarkably.

Sources of irradiation

Rawat *et al*., (2015) [8] stated that irradiation an essential requirement for the industrial use of food irradiation is an economic source of radiation energy. Two types of radiation source can satisfy this requirement today: machines and man-made materials. Although they differ in the method of operation, both types of source produce identical effects on foods, microorganisms, and insects. Machines called electron accelerators produce electron radiation, a form of ionizing radiation. Electrons are sub-atomic particles having very small mass and a negative electric charge. Beams of accelerated electrons can be used to irradiate foods at a relatively low cost. this cost advantage is offset, however, by the fact that accelerated electron beams can penetrate food only to a maximum depth of about 8 em, which is not deep enough to meet all the goals of food irradiation. Accelerated electrons are, therefore, particularly useful for treating grain or animal feed that can be processed in thin layers; electron beam irradiation is particularly suitable for these applications because of the very high throughputs involved in grain handling.

Charlesby *et al*. (2009) [16] studied man-made radionuclides constitute the other main source of ionizing radiation; radionuclides are radioactive materials that, as they decay give off ionizing gamma rays that can be used for food processing. One radionuclide that is readily available in large quantities is cobalt-60, which is produced by exposing naturally occurring cobalt-59 to neutrons in a nuclear reactor. The availability of another radionuclide, caesium137, a by-product of nuclear reactor operations, is limited and it is not used widely at present. Gamma rays from either of these radionuclides will penetrate deeply enough to meet virtually all food irradiation needs. The cost of man-made radionuclide sources is considered acceptable for industrial food irradiation in view of the great versatility and penetrating capacity of the gamma-rays.

Doses of irradiation and studies

Low dose of irradiation

Mustafa *et al*. (2013) [10] analysed low doses of irradiation can be applied to several types of food products such as tubers, fresh fruit and vegetables, cereals or nuts and seeds, dried vegetables and spices, and dry food of animal origin. Irradiation aims to delay ripeness, eradicate insects, and control quarantine for some fresh fruits and vegetables. Irradiation of tubers seeks to inhibit the germination process. In cereals or nuts and seeds aims to eliminate insects. Meanwhile, irradiation of dry vegetables, spices, or dry herbs and tea herbs is intended to eradicate insects. Dry food derived from animals also has the same goal, namely, to eliminate insects. Recommendations or regulations regarding irradiation in low doses of food products are available based on the BPOM Republic of Indonesia. The minimum dose is 0.2; 1.0; 1.0; 1.0; and 1.0 kGy, respectively found in tubers; fresh vegetables and fruits; cereals, beans and seeds; dry vegetables and spices; and dry food from animal sources

High dose of irradiation

Wojcik *et al*. (2019) [11] reported that high levels of irradiation can be applied to food items, such as dried spices and animal-based ready-to-eat food. Each irradiation process that is carried out has a different purpose. Irradiation of some dried herbs has the aim of reducing certain pathogenic microorganisms. Meanwhile, animal-based ready-to-eat processed food products have the objective of sterilizing and eradicating pathogenic microbes, including microbes with spores and extending shelf life. There are regulations regarding irradiation in high doses of food, including some dry spices with a minimum dose of 10.0 kGy.

Ehlermann *et al*. (2016) [12] studied irradiation can change the chemical compounds in food to change these products' nutritional value in nutritional aspects. The study results showed that nutrient loss in food irradiated with 1 kGy dose had no significant impact. In comparison, moderate-dose irradiation (1-10 kGy) may reduce its nutritional components unless the irradiation process's temperature and air are adjusted in this way. Proper treatment, such as combined radiation conditions with packaging techniques, will maintain processed food products' quality and nutrition.

Younis *et al*. (2020) [13] examined the benefits of using irradiation in food are little or no heating process, so the material doesn't change its characteristics. Also, irradiation can suppress microorganisms that live in food. Irradiation can be carried out on packaged foods, frozen foods, and fresh food through one operation and do not use chemical additives. Irradiation requires only a small amount of energy, nutrition changes can be compared with other preservation methods, the automatic process is controlled, and the operating costs are low.

Use of irradiation in food processing/preservation

Zhao *et al*. (2017) [37] reported that irradiation food preservation uses high energy, known as ionizing radiation. It is because the material in its path can be ionized. When irradiation sources such as X-rays, gamma rays, and electron beams touch the material, these food components will be excited, ionized, and altered. An excitation is an event where living cells become sensitive to external conditions. Ionization is the process by which macromolecules are broken into free radicals. Changes in living cell components will inhibit DNA synthesis, disrupting microbial cell division, and biological effects. This effect inhibits microbial growth in food. Some of the benefits of using irradiation in food are little or no heating process, so the material doesn't change its characteristics. Also, irradiation can suppress microorganisms that live in food. Irradiation can be carried out on packaged foods, frozen foods, and fresh food through one operation and do not use chemical additives. Irradiation requires only a small amount of energy, nutrition changes can be compared with other preservation methods, the automatic process is controlled, and the operating costs are low.

Sood *et al*. (2020) [13] observed that each food ingredient irradiated with a different purpose has an extra dose depending on the food itself characteristics. The rays commonly used to preserve food products with irradiation are gamma rays, X-rays, and electron beams, each of which has its advantages and disadvantages. Chemical, nutritional, microbiological, and toxicological aspects are used for food irradiation safety parameters. The principle of radiation is excitation, ionization, and changes in components contained in foods when the radiation source touches the material. The irradiation process has advantages and disadvantages, one of which is that the radiation process does not use heat so food does not change its characteristics. However, the irradiation process is still a public fear of radioactive influence on foodstuffs. Irradiation can be applied to foods by paying attention to the dose according to the foodstuff.

Effect of food irradiation

Urbain *et al*. (2012) [32] stated that at high energy levels, ionizing radiation can make certain constituents of the food radioactive. Below a certain threshold of energy, however, these reactions do not occur. On the basis of experimental studies and theoretical estimates, in 1980, the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Foods recommended restricting the radiation sources used in food processing to those with energy levels well below those that induce radioactivity in treated food. Food processed by radiation in accordance with the Committee's recommendations does not become radioactive. However, the chemical composition of food can be altered by radiation, and authorities responsible for assessing the safety of irradiated food have had to consider the possibility that some of the chemical compounds formed during food irradiation may be harmful. In recent years, radiation chemistry has been recognized as an additional tool for toxicological evaluation, and the methods involved have been substantially refined. As a result, answers to questions about the safety of irradiated food can be extrapolated with reasonable confidence on the basis of information about the chemical composition of foods and the radiolytic effects (Chemical changes caused by irradiation) produced under various conditions.

Effect of irradiation on mechanical properties of grain

Padmashree *et al*. (2016) [14] reported that IR radiation-induced remarkable changes in the mechanical and physical properties of the grain. It resulted in a decrease in elasticity modulus, bio-yield point and the compression resistance resulting in an increase in stiffness, and breakage susceptibility as studied in case of barley, lentils, kidney bean, black bean and pinto bean. These changes were attributed either to the starch gelatinization during heating or to the fissuring of the grain surface. In case of buckwheat, IR radiation reduced the bulk density which was attributed to the diffusion of water from inside to outside, resulting in volume expansion. The exposure of wheat grain with IR radiation increased the kernel hardness which was attributed to the interaction between starch and protein. The removal of moisture during IR heating might have exposed the free atoms in both starch and protein subsequently facilitating their interaction. In case of rice, the IR heating increased milling yield due to the uniform heating and less moisture gradient. Apart from the uniform heating mechanism of IR radiation, the phenomenon of increased hardness might also have contributed to the improved milling yield.

Sciarini *et al*. (2015) [15] reported that IR treatment on wheat grain can significantly affect particle size of the bran and flour, thus improving their functional properties. Similarly, IR irradiated lentil flour particles were of smaller size compared to non-irradiated. Author also observed that the particle size of the lentil flour irradiated with IR at lower temperature and higher moisture content had larger particle size due to clumping of the particles. Hence, IR thermal treatment might be considered as an alternative green technology to reduce the flour particle size, where moisture content is a critical factor. Although the reduction in particle size could also be achieved by regrinding, it caused a higher degree of starch damage and affected final product quality. The IR radiation cause physicochemical changes in grain starch, such as changes in moisture content, solubility, and swelling ability. The extent of the aforementioned changes depends on the starch type, moisture content, exposure time, processing temperature and absorption of IR thermal energy.

Sukalovic *et al*. (2010) [17] stated that the IR radiation interacts with grain and its components in an interesting way by vibrating the bonds causing it to stretch, unlike the conventional thermal treatment and has an ability to modify characteristic properties of the starch. Since, starch is the major component of grain, any change in the above observed properties of starch in turn changes the mechanical and functional properties of the grain, and therefore starch characteristics defines the final application in the food industry. The IR treatment of grains reduces the energy requirement during flour milling due to the reduced compression resistance, rupture force, modulus of toughness and elasticity. This resulted in an increase in the milling yield and hence, reducing the cost input in the flour milling industry. The additional feature of IR radiation is the ability to modify the functional properties of the grains/flours/starches, and influences the end use. IR irradiated starches had increased final viscosity, water absorption capacity, and water swelling indices, such modified starches can find applications in the formulations such as puddings, soups, dressings, gravies and sauces.

Effect of irradiation on functional properties of grain

Rastogi *et al*. (2015) [18] reviewed the properties like extensibility, viscosity, etc. are considered as a key macroscopic property in the formation and development of food products. One of the factors affecting rheological properties is thermal energy. Several studies have shown that the IR irradiation caused a reduction in the hot paste consistency and in peak and breakdown viscosities as observed in wheat and corn starch. The decrease in breakdown viscosity was attributed to the reduced ability of starch granules to swell and to the reduction in the proportion of long amylopectin chains during treatment. An increase in cold paste viscosity was also noticed and it was attributed to the increased resistance of starch granules to the breakage. Another study on rice revealed that the annealing of starch and denaturation of protein could reduce the peak and final viscosity. Similar changes in the pasting properties of maize, lentils, and buckwheat were also reported. The IR treatment also reported to decrease set back and final viscosity in mung bean, which was attributed to the inability of disrupted starch to realign itself during retrogradation. Yet another study on IR treated maize reported similar reductions in final viscosity of IR-treated maize due to changes in the starch structure and solubility of the protein. The IR radiation-induced changes in the wheat starch, and protein which in turn reduced the values of farinograph, mixogram, and extension graph for the wheat dough, which could be disadvantageous in the bakery industry as it reduces the dough stability and extensibility.

Ding *et al*. (2016) [19] studied the IR radiation-induced changes in the wheat starch, and protein which in turn reduced the values of farinograph, mixogram, and extension graph for the wheat dough, which could be disadvantageous in the bakery industry as it reduces the dough stability and extensibility. However, a reduction in dough development time was reported. The above studies clearly demonstrated that the disintegration of starch granules causes the reduction in values of pasting profile in all the IR treated grains and starches, except waxy varieties of barley indicating the importance of amylose in deciding the rheological properties. In addition to starch, the protein content also seemed to affect the rheological properties which might be the reason for the difference in the behaviour of monocots and dicots to IR radiations. These changes in the rheological properties of starches and grains have implications in their final application in the food industry. Also, the insight of these changes by IR radiation might assist in optimizing processing parameters such as time, moisture content and energy input. IR radiation caused an increase in peak, setback, breakdown, and final viscosity of the tempered and non-tempered waxy variety of barley, whereas a reduction in breakdown viscosity of normal barley commensurate with the increase in pasting temperature. The author opined that the increase in viscosity of waxy barley is due to the increase in swelling ability of starch, whereas in case of normal barley, starch becomes resistant to lysis and remain stable at higher temperature. However, the interaction between the starch and protein could also play an important role in modifying the swelling ability of starch.

Effect of irradiation on sensory/nutritional properties

Josephson *et al*. (2015) [20] reported that the high radiation dose required for sterilization has been associated with unwanted flavour changes in some food, and it appears that the change occurs in the lean rather than the fat portion of some food. it decreases or disappears during storage and cooking. Investigators have also observed that particle of food irradiated at low temperature is less liable to flavour change. Enzyme-inactivated food products that received about 50 kGy of radiation at a temperature of -30 °C for long-term shelf-stability. The chemical changes that radiation produces in food may lead to noticeable effects on flavour. The extent of these effects depends principally on the type of food being irradiated, on the radiation dose, and on various other factors, such as temperature, during radiation processing. Some foods react unfavourably even to low doses of radiation. Milk and certain other dairy products are among the most radiation sensitive foods. Doses as low as 0.1 kGy will impart an off-flavour to milk that most consumers find unacceptable.

Wojick *et al*., (2019) [11] studied that food processing and preparation methods in general tend to result in some loss of nutrients. As in other chemical reactions produced by irradiation, nutritional changes are primarily related to dose. The composition of the food and other factors, such as temperature and the presence or absence of air, also influence nutrient loss. At low doses, up to 1 kGy, the loss of nutrients from food is insignificant. In the medium dose range, 1-10 kGy, some vitamin loss may occur in food exposed to air during irradiation or storage. At high dosages, 10-50 kGy, vitamin loss can be mitigated by protective measures - irradiation at low temperatures and exclusion of air during processing and storage. The use of these measures can hold the vitamin loss associated with high dosage to the levels seen with medium-range doses when protective measures are not employed. Some vitamins- riboflavin, niacin, and vitamin D- are fairly insensitive to irradiation. Others, such as vitamins A, B, E, and K are more easily destroyed. Little is known about the defect of irradiation on folic acid, and conflicting results have been reported concerning the effects of irradiation on vitamin C in fruits and vegetables.

(Charlesby *et al*., 2009) [16] examined the significance of radiation-induced vitamin loss in a particular food depends, of course, on how important that food is as a source of vitamins for the people who consume it. For example, if a specific food product is the sole dietary source of vitamin A for a given population, then radiation processing of that particular food may be inadvisable because it could greatly reduce the availability of this essential nutrient. Furthermore, since many irradiated foods are cooked before use, the cumulative loss of vitamins through processing and cooking should be taken into account. Chemical analyses and animal feeding studies have shown that the nutritional value of proteins is little affected by irradiation, even at high doses. Animal studies in various species have also demonstrated that the effects of radiation on other nutrients are minimal.

Effect of irradiation on gluten and protein content of wheat

Sapirstein *et al*. (2017) [33] studied the influence of gamma irradiation on the rheological behaviour of the dough's obtained from the three wheat cultivars with a micro-mixograph. The corresponding effects of irradiation on the composition of 50 PI glutenin were assessed by both SDS-PAGE and quantitatively by RP-HPLC. Mixograph peak mixing times and work input to peak values significantly decreased (p<0"05) for all cultivars as irradiation level increased. A similar decrease in peak dough resistance and band envelope area values were also observed with increasing radiation exposure. However, the decrease was significant only for the bread wheat cultivars at the 10 and 20 KGY levels. Significant reductions in peak bandwidth were evident at 10 and 20 KGY irradiation levels for all wheat cultivars. The high, and mostly significant, negative correlations between irradiation dosage and mixograph parameter for all cultivar samples underscores the adverse effect of irradiation on dough mixing characteristics. It has previously been reported that rheological properties of dough's change when bread wheat 4'6 or durum wheat are irradiated. In the present study, irradiation resulted in a weakening effect on the mixing properties, which was more severe at 10 KGY or higher. These findings confirm that wheat gluten has been affected.2 g direct drive mixograph was utilised for the first time for the evaluation of irradiated wheat samples. Because of the computed parameters, it was possible to show the effects of irradiation on rheological properties more clearly than by using the standard mixograph. When this result was explored further, it was found that compared to non-irradiated wheat, the relative decline in total insoluble glutenin at the 20 kGy dosage level ranged from 34% (Be-zostaya) to 47 and 49% (Gerek and Kunduru) respectively.

Johnson *et al*. (2011) [34] observed that gamma-irradiation at the levels investigated had no effect on proteins. In contrast to the gliadins, a significant effect of wheat irradiation was observed in SDS-PAGE patterns of reduced 50 PI glutenin of all cultivar samples; the effect was particularly noticeable at the 10 and 20 kGy dosage levels for the HMW-GS and LMW- GS whose relative intensities decreased considerably compared to control or 2"5-5"0 kGy irradiated samples. It is worth pointing out that the observed decrease in band intensities of HMW- and LMW-GS was more apparent in the original gels than in the corresponding photo-graphs. Quantitative RP-HPLC results confirmed that the concentration of all subunits of the 50 PIglutenin fraction were similarly affected by the irradiation treatments. These results clearly showed that the total peak area of the 50PI glutenin chromatograms decreased significantly (P<0-05 for all wheat cultivars as irradiation level increased. Similar significant decreases were observed for HMW- and LMW-GS. As was observed for mixograph parameters, correlations between irradiation level and 50 PI glutenin composition parameters were high, negative, and generally statistically significant.

Effect of irradiation on starch and structure of starch

Pan *et al*. (2011) [35] studied the thermal treatment influences the basic structure of the starch, which in turn affects its digestibility pattern. There are several studies on cereals and legumes to understand the effect of IR radiation on *in vitro* starch digestibility. The exposure of IR radiation on normal, high-amylose and waxy barley increased starch digestibility.

At the same time, IR irradiated waxy barley samples contain substantially less amount of resistant starch (RS), The IR radiation had a similar effect on the starch digestibility pattern in cereals, while variations were observed in the case of legumes which might be due to the distribution of starch and protein within the grain. Pulses contain more protein (20-40%) than cereals (1012%). Therefore, protein bodies surrounding starch granules might be the reason for the lesser impact of IR radiation on starch digestibility. The significance of particle size, while assessing the impact of radiation, could be accounted for the differences in the digestibility pattern in-situ and *in vitro*. The difference in *in vivo* and *in vitro* studies yielded opposite results suggesting the limitation of the *in vitro* analysis in mimicking the biological system and its complexity. Therefore, to arrive at a concrete conclusion on the effect of IR radiation on starch digestibility, more scientific insights based on clinical studies are required. Birefringence for native starch granules exhibits a characteristic “maltese cross” at the centre of granules that can be visualized in polarized light. The wheat starch treated with IR radiation at 100 C for 10 and 20 sec did not show any change in the maltese cross. The wheatstarch treated at 750 W power at 30% moisture for 90 min ruptured the granules with black spots at the centre.

Bualuang *et al*. (2013) [38] reported that IR is capable of altering the mechanical and functional properties and starch digestibility pattern of the grain, due to the changes in the structure of starch. The starch granules are spherical or polygonal in shape and exhibit a characteristic birefringence and a diffraction pattern when exposed to polarized light and X-rays respectively. Any change in the birefringence or diffraction indicates the change in the crystalline and amorphous structure of starch. The IR treatment of soft wheat decreased the degree of crystallinity of starch by approximately 26%. Another study showed that IR irradiation of wheat starch at 730 W with 30% moisture for 60 and 90 min changed its native A-type diffraction pattern to V-type with a decrease in relative crystallinity which was attributed to the transformation of the crystalline region to an amorphous region. This transformation in starch was linked to the complex formation of amylose with fatty acids and phospholipids with a V-crystal packing resulting in the V-type diffraction pattern. The IR irradiation of corn starch at 20% moisture and 550 W for 90 min showed a similar change in the diffraction to V-type but with an increase in crystallinity which was attributed to the displacement of double-helical chains to a more orderly arranged structure. As in case of cereals, IR irradiated common bean showed changes in diffraction from native C-type to V type and an increase in crystallinity, which was related to the formation of amylose-lipid complex. The above observations suggested that the IR treatment converts starch ultimately to V-type, irrespective of the plant source.

Application of food irradiation

Becker *et al*. (2016) [36] studied that there is a minimum dose for each application of food irradiation below which the intended effect will not be achieved. The dose requirements for some typical uses of food irradiation. Because irradiation causes only a slight temperature rise in the food being processed, it can kill microorganisms without thawing frozen food. Moreover, an effective radiation dose can be delivered through most standard food packaging materials, including those that cannot withstand heat. This means that irradiation can be applied to hermetically sealed products without the risk of recontamination or re-infestation of properly packaged foods. Some food products may have to be irradiated under special conditions, for example at low temperature or in an oxygen-free atmosphere. Others, as noted previously, may undergo multiple processing, using, for example, both ionizing radiation and heat. This particular combination may allow the use of lower radiation doses because heat makes microorganisms more sensitive to the effects of radiation. Since radiation does not damage packaging materials designed to hold food during irradiation, multiple processing is facilitated and is more economical.

Insect disinfection, radiation disinfestations can contribute significantly to improving trade in certain tropical and subtropical fruits, such as citrus fruit, mangoes, and papayas. Because it affords a residue-free means of preventing the importation of harmful insects, radiation treatment offers a viable alternative to fumigation to satisfy the quarantine regulations in a number of countries. Fruit flies, for example, and even the weevil that lodges deep inside the seed of the mango can be controlled by irradiation.

Shelf-life extension of perishable foods, The shelf-life of many fruits and vegetables, meat, poultry, and fish and other seafood’s can be considerably prolonged - certainly doubled - by treatment with combinations of refrigeration and relatively low doses of radiation that do not alter flavour or texture. Most food spoilage microorganisms are killed at doses of less than 5 kGy. Various fresh fruits, including strawberries, mangoes, and papayas, have been irradiated and marketed successfully. A combination of mild heat treatment (immersion in hot water), low-dose irradiation, and proper packaging may be successfully applied to fruits that are sensitive to higher radiation doses.

Destruction of parasites, Irradiation inactivates certain parasitic organisms that are responsible for both human and animal diseases. The parasitic roundworm Trichinella spiralis, which causes trichinosis and is found in pork, is inactivated by radiation at a minimum dose of 0.15 kGy. Other parasites, including pork and beef tapeworms, the protozoon in pork responsible for toxoplasmosis, and various flukes that infest fish are rendered non-infective by low-dose radiation treatment.

Conclusion

Each food ingredient irradiated with a different purpose has an extra dose depending on the food its elf’s characteristics. The rays commonly used to preserve food products with irradiation are gamma rays, which has its advantages and disadvantages. Chemical, nutritional, microbiological, and toxicological aspects are used for food irradiation safety parameters. The principle of radiation is excitation, ionization, and changes in components contained in foods when the radiation source touches the material. one of which is that the radiation process does not use heat so that food does not change its characteristics. However, the irradiation technique is predominately used to enhance the shelf life by inactivation of microbial activity and there is no adverse effect on nutritional value, rheological properties and functional properties of irradiated food. Thus irradiation has no adverse effect on nutritional properties of wheat flour i.e protein, fat, ash, antioxidant, phenolic content.

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