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Irradiation of Starch and Its Effect on Pasting Properties: A Review

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A B S T R A C T

Starch is the most abundant carbohydrate from the plant source.In different food processing sectors starch plays a vital role, includes thickening, gelling, consistency and shelf stability in various food applications. Irradiation plays an important role on the starch modification, it improves the viscosity of starch and plays a key role in the pasting properties. Irradiation dose was positively correlated to solubility and negatively correlated with relative crystallinity, thermal properties, and pasting properties

Introduction

Starch is the most abundant carbohydrate reserve in plants and is found in leaves, flowers, fruits, seeds, different types of stems and roots. Starch is used by plants as source of carbon and energy (Smith, 2001).In food processing industries, starch contributes a variety of vital features which includes thickening, gelling, consistency and shelf stability in varied applications (Considine and Considine, 1982). Starch can be isolated from potato, rice, corn and wheat that has been exclusively used to confer the structure, texture, consistency and appeal to many food and non-food products (Jobling, 2004). Native starches have some of the limitations such as low shear and thermal resistance as well as high affinity towards the retrogradation. The starches may need to be modified for their adaptability to the areas of application by improving the physico-chemical and functional characteristics (Bao and Corke, 2002).Biochemical chain responsible for the starch synthesis of the glucose molecules that are produced in the plant cells is by photosynthesis. Starch is formed in the chloroplasts of green leaves and amyloplasts, organelles that are responsible for the starch reserve synthesis of cereals and tubers (Smith, 2001; Tester *et al.,* 2004). Starch production in the chloroplasts is diurnal and performed rapidly by the plant and the starch reserves produced by the amyloplasts are deposited over several days, or even weeks. Starch is stored and cyclically and mobilized during seed germination, fruit maturation and the sprouting of the tubers (Ellis *et al.,* 1998).

The main location of starch synthesis and storage in cereals is in the endosperm. The major sources for the starches are cereals is about 40 to 90%, in roots it is about 30 to 70% in tubers it is about 65 to 85% and in legumes it is about 25 to 50% and some immature fruits like bananas or mangos, which contain approximately 70% of starch by dry weight (Santana and Meireles, 2014). The increasing pattern of starch granules in each plant tissue, shape, size, structure and composition is unique in each species (Smith, 2001).

Starch synthesized by plant cells is formed by two different types of polymers they are amylose and amylopectin. Amylopectin consists of linear chains of glucose units linked with α-1,4 glycosidic bonds and it is highly branched at the α-1,6 positions by small glucose chains at intervals of 10 nm along the molecule's axis and it constitutes in between 70 to 85% of the common starch (Durrani and Donald, 1995). Amylose contains an essential linear chain of α-1,4 glucans with limited branching points at α-1,6 positions and it constitutes 15-30% of the common starch. Structural starch contains chains contain amylose and amylopectin. The polymodal distribution of α-glucans chains of different sizes and the grouping of branch points in the amylopectin molecule allow the formation of double helical chains. Amylose and amylopectin can be arranged in a semi-crystalline structure forming a matrix of starch granules with alternating amorphous (amylose) and crystalline (amylopectin) material, which is known as the growth rings in superior plant starch (Jenkins *et al.,* 1993).

Physical modification of starch:

The physical modification methods of starch is accomplished by different methods which includes the gamma irradiation, microwave (Lewandowicz *et al.,* 2000), ultraviolet (Bertolini *et al.,* 2001; Fiedorowicz *et al.,* 1999), ultrahigh hydrostatic pressure (Katopo *et al.,* 2002), and hydrothermal treatment (Jacobs and Delcour 1998). Gamma irradiation generates the free radicals on starch molecules which alter the molecular size and structures (Sabularse *et al.,* 1991). Different studies were performed on the effects of ionizing radiation on wheat starch (Lai *et al.,* 1959), barley endosperm and corn starch (Faust and Massey 1966; Kang *et al.,* 1999).

In the physical method of modification of starch heat and moisture treatment is one of the major method. Different starches were subject to acid hydrolysis combined with heat and moisture treatment. In comparison with the native starches, the swelling power of all the modified corn starches decreased at different treated conditions with 75 °C of temperature, and the solubility of the most of the modified starches were increased. The gelatinization temperature of the modified starch was increased. But Peak viscosity, trough viscosity and break down viscosity of most heat and moisture treated starch samples were lower than those of native starch. However, when pH was 1, gel of starch sample was not formed. After Heat and moisture treatment, the hardness of the most modified starch gels increased significantly.

The maximum hardness of modified starch gel is about 148.419 g with improving about 93.471 g which is in comparison with native starch gel. The melting temperature of modified starch is increased, but the melting range is decreased in the heat and moisture treated starch. The X-ray pattern of the starch is remained practically unchanged with or without heat and moisture treatment and it can improve the physical and chemical properties of corn starch and this heat and moisture method provides some practical information on the potential usefulness of corn mixtures in the food industry (Sun *et al.,* 2015)

Chemical modification of starch

Chemical modification is the most common way to modify the starch but there is always a concern regarding usage of the chemicals especially when they are used for different food products. Now a days the modern non-conventional methods of starch modification includes the physical techniques which are very fast, low cost and environmental friendly because they do not use pollution causing agents as well as they do not allow penetration of toxic substances in the treated products. Among all the physical techniques, irradiation is very well accepted as there is no significant rise in the temperature and it is a rapid process, non-reliance on any other type of catalysts and requires very less sample preparation. Irradiation involves the use of gamma-rays by using cobalt 60 as a source, in which the food products are directly exposed to that rays. It is an ionic non-heating processing technology which is used as an functional modification agent in polymer research and application.

Food products that are prepared by using gamma irradiation have improved durability, extended shelf life and it is nutritionally adequate and safe for the human consumption. It is responsible for inducing the several changes in starch like de polymerization and degradation which often results in the decreased viscosity and cross linking. The process of irradiation method increases the durability of foods with respect to extension of shelf-life (Chung and Liu, 2010). These changes results in the increased solubility and decrease in the swelling power and viscosity of starch. It causes hydrolysis of chemical bonds of starch into smaller fragments of dextrin, which can be either electrically charged or uncharged as free radicals. Sonication (with ultrasound) is an another method of physical treatment which is also an emerging technology that can be considered as simple, reliable, inexpensive technology and it is an environmentally friendly. Sonication is a process in which the sound waves are used to agitate particles in a solution. When the ultrasonic energy propagates in the liquid, cavitation bubbles are formed due to pressure changes. These bubbles collapse violently as the sound wave propagates, resulting into regions of high temperature and pressure. The aim of the present study was to evaluate the effect of dual modification of sonication and gamma irradiation on physicochemical and functional properties of lentil starch (Majeed *et al.,* 2017).

Gamma irradiation degrades the glycosidic bonds which results in conversion of large starch molecules into smaller fragments. These changes may affect the physicochemical properties of the foods which are irradiated (Kang *et al.,* 1999; Wu *et al.,* 2002). The food products that are irradiated with gamma-irradiation have been established to be both nutritionally adequate and safe for consumption of humans (Chung and Liu., 2010; WHO, 1999). Apart from food industries, starches modified with the gamma-irradiation at higher doses are applicable in the different industries like textile and paper (Roushdi *et al.,* 1983). The free radicals formed by the process of irradiation are involved in the formation of smaller fragments from large granules of starch by the breakdown of the glycosidic bonds (Yu and Wang., 2007; Sokhey and Hanna, 1993). Gamma –irradiation results the smaller fragments from the starch molecules which shows a low molecular weight change in the pasting viscosity and increase in solubility and acidity (Yu and Wang., 2007; Rayas-Duarte and Rupnow., 1993). Improvement of overall nutritional attributes and some desired changes in the functional properties of different flours have improved by using the ionizing radiations (Rahma & Mostafa, 1988; Dario & Salgado, 1994; Dogbevi, Vachon, & Lacroix, 2000). The study on the irradiated foods by joint FAO/IAEA/WHO study group concluded that application of ionizing radiation at 10 kGy or higher doses will be safe and nutritionally adequate (WHO, 1999).

Changes in the starch during gamma irradiation

Gamma irradiation is a convenient method for the modification of starch polymers through cross-linking, grafting and degradation. It is also suggested that gamma irradiation is a rapid and convenient modification technique which breaks large molecules into smaller fragments and is capable of cleaving glycosidic linkages (Kang *et al.*, 1999; Yu and Wang, 2007) Gamma-irradiation at a dosage of 0.2–2.0 kGy controlled the insects in packaged aromatic milled rice. Gamma irradiation induces so many physicochemical changes in the rice, decrease in the pasting parameters, increases in the water absorption capacity and total solids in the cooking water, and decreased cooked rice hardness showed the starch granules of milled rice were changed by irradiation. Several alterations on the granular structure of starch were seen with the scanning electron microscope and finally the changes in the rice affected the texture of the cooked rice (Sirisoontaralak and Noomhorm, 2006).

The main purpose of irradiation of grains and other foods is to protect them from insect infestation and microbial contamination during the period of storage. It has an important effects on various quality criteria of cereals. Different experiments havebeen performed to study the effects of irradiation on various aspects of wheat, rice, and maize quality. As we discussed earlier the depolymerization of starch by irradiation as the quality traits are mainly related to the starch properties. Free radicals produced by the irradiation modify the amount and structure of starch fractions. Granule structure remains undamaged at low dose of irradiation but it suffers severe damage at higher doses of irradiation (100 kGy). The crystallinity of the irradiated starch becomes higher with increasing the radiation doses in the starches like corn and rice. Increase in the irradiation dose is invariably associated with lower viscosity and higher water solubility and the acidity in the starch. Swelling power is generally very low, but may become higher at 20 kGyof irradiation treatment, and then declines rapidly. Gelatinization enthalpy in the grains were increased gradually with increasing the irradiation dose. The peak temperature of gelatinization became higher only at 20 kGy on the irradiation of dry bean starch. The irradiation dose at 2 kGy made retro gradation of lasco triticale and grana wheat starches lower and higher respectively. The chain length of amylose and amylopectin shows a progressive reduction with increase in the irradiation dosage. Gel permeation chromatographic separation clearly showed that mostly amylopectin is subject to more degradation due to irradiation (Bao and Corke, 2002).

The pasting properties of starch is changed by the gamma irradiation in the values of pasting temperature which is not a significant for lower doses (10 kGy), but above 20 kGy irradiation dose treatment, the value of pasting temperature is significantly decreased. The change in the pasting temperature is not observed on the gamma irradiated starch at a dose of 500 kGy. In general, the pasting temperature, is a temperature when viscosity of starch increased sharply, was always higher than gelatinization temperature. Ultra-high irradiation dose induced by the gelatinization of starch solution is gelatinized at room temperature. The low pasting temperature of starch indicates their lower resistance towards swelling (Sandhu and Singh, 2007).

Gamma-irradiation did not change the surface structure of starch granules up to 500 kGy of irradiation dose level. Gamma-irradiation increased the solubility of starch significantly and decreased the pasting properties such as pasting viscosity, trough viscosity, final viscosity and set back viscosity respectively. With increase in the irradiation dosage more than 50 kGy, break down viscosity decreased significantly. The decrease in setback viscosity and break down viscosity indicated that higher irradiation doses reduced the stability of starch pastes and their tendency towards the retrogradation. Upto 200 kGy of irradiation dose and the intensity of bands corresponding to the amorphous part of the starch structure is observed to decrease. Irradiation dose was positively correlated to solubility and negatively correlated with relative crystallinity, thermal properties, and pasting properties (Liu *et al.,* 2012)

Pasting properties such as peak, final and setback viscosities are decreased with increase in the irradiation on brown rice starch. Pasting temperature significantly decreased with increase in the irradiation in all starches. The apparent amylose content, enthalpy of gelatinization and transition temperatures, of starch decreased significantly with increase in irradiation, swelling index is decreased with increase in the irradiation dosage. Irradiation also decreased the percentage of crystallinity in the granules as the irradiation dose is increased and the surface structure was not affected. Irradiation of brown rice starch decreased the peak, setback, trough and final viscosities of the starch in which the solubility index is increased. Gamma irradiation improved some of the functional properties of the starch like decreased retrogradation, decreased gelatinization enthalpy and hence irradiation is used as an quick method for starch modification which can be used in the food industries. The reduction in the retro gradation can be very important in using the modified starch in frozen foods (Pradeep Kumar *et al.,* 2017)

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