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Review

The use of gamma irradiation in agriculture

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Lately, radiation technology is widely used to produce changes in the product characteristics leading to the development of new products. Gamma irradiation is capable of hydrolyzing chemical bonds, thereby cleaving large molecules of starch into smaller fragments of dextrin that may be either electrically charged or uncharged as free radicals. These changes may affect the physical and rheological properties of irradiated foods, resulting in increased solubility of starch, decreased swelling power, and decreased viscosity of starch paste. Irradiation of gamma rays on bud wood can produce higher frequencies of mutation, leading to the creation of new variants compared to the control. Macronutrients (carbohydrates, proteins and lipids) content are relatively stable against irradiation doses up to 10 kGy, on the other hand, gamma irradiation affects proteins by causing conformational changes, oxidation of amino acids, rupturing of covalent bonds and formation of protein free radicals. Radiation mediated morphological, structural and functional changes in a plant are governed by the intensity and duration of the gamma irradiation.

Key words: Irradiation, Foods sterilized, Mutation, Biochemical change, Agriculture.

INTRODUCTION

Irradiation is an ionic, no-heat process that continues to receive attention as a preservation and functional modification agent in polymer research and application (Abu et al., 2006). It was considered as one of the physical modification methods of nature polysaccharide (Hai et al., 2003; Relleve et al., 2005; Rombo et al., 2004). In comparison with other physical modification methods, such as microwave, UV, ultrahigh hydrostatic pressure and hydrothermal treatment, irradiation treatment is rapid, convenient and more extensive because ionizing energy penetrates through the polysaccharide granule rapidly (Bao et al., 2005). This process is useful in solving various agricultural problems: reduction of post-harvest losses through suppressing sprouting and contamination, eradication or control of insect pests, reduction of food-borne diseases and in extension of shelf life, and breeding of high performance well adapted and disease resistant agricultural crop varieties (Andress, 1994; Emovon, 1996).

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Mutation

Nuclear techniques, in contrast to conventional breeding techniques, are widely applied in agriculture for improving genetically diversity. Unlike conventional breeding procedures which involve the production of new genetic combinations from already existing parental genes, nuclear technology causes exclusively new gene combinations with high mutation frequency. Basic tool of nuclear technology for crop improvement is the use of ionizing radiation which causes induced mutations in plants. These mutations might be beneficial and have higher economical values (Abdul et al., 2010).

Mutagenesis has already been used to improve many useful traits affecting plant size, flowering time and fruit ripening, fruit color, self compatibility, self thinning, and resistance to pathogens. Nowadays, the number of cultivars derived from mutation induction increases constantly (Hearn, 2001; Maluszynski et al., 1995). Inducing mutations by gamma rays has been effectively used with several species of Citrus. Irradiation of gamma rays on bud wood can produce higher frequencies of mutation leading to the creation of new variants compared to the control. Radio sensitivity (LD 50) of acute exposure of Citrus ranges from 40 to 100 Gy (Sanada and Amano, 1998; Sparow, 1968) depending on species and varieties. Scion (bud wood), seeds, foral stage embryos, and *in vitro* material of Citrus were exposed to gamma rays. Citrus sunki was irradiated with 20 or 40 Gy of gamma rays at three different foral stages (Spiegel-Roy and Padova, 1973) and nucellar seedling (Ikeda, 1976). A spine free mutant was selected from irradiated nuclear. In Citrus sinensis, immature seeds were exposed to gamma rays at the doses 80-100Gy (Sparow, 1968), while those polyembryonic seeds were exposed to gamma rays of 100Gy (Kukimura, 1976). Two seedless mutants were selected, leading to release of a new cultivar “Hongju 418 and Hongju 420” (Kukimura, 1976). Citrus paradisi cv Hudson were exposed with thermal neutron, leading to release of a seedless mutant ‘Star Ruby’ (Chen, 1991). Another fve nearly seedless mutants of Citrus paradisi cv Foster were also selected from irradiated bud wood at the dose 50 gray of gamma rays (Micke, 1985). Citrus limon cv Eureka and Israeli Villafranca were irradiated by 60 and 50 Gy of gamma rays respectively, and completely new seedless varieties were released (Hearn, 1985). A red color of flesh and juice mutant derived from 80 Gy gamma irradiation of Citrus paradisi cv Ruby Red was released as cultivar Rio Red in 1984 (Spiegel-Roy, 1985). Bud woods of pummel, mandarin and Navel Orange irradiated by gamma-rays at doses of 30 to 75 Gy showed high sensitivity at higher dose, while Valencia and grapefruit produced more seedless fruits from those at the higher doses (Wu, 1986). Khatri et al. (2005) collected three high grain yielding and early maturing mutants by treating seeds of *Brassica juncea L*. cv. S-9 with gamma rays (750 to 1000KGy) and EMS.

Shah et al. (2001) developed a new oil seed *Brassica napus* L cv. ABASIN-95 by induced mutation. They exposed seeds of B. napus L. cv. Tower to 1.0, 1.2 and 1.4 KGy gamma rays and the resulting new variety was high yielding, resistant to Alternaria blight and white rust.

Irradiation of gamma rays (10-60 Gy) on calli in vitro proliferation stage resulted in high mortality at the dose of 60 Gy (Predieri, 2001) When nucellus and embryonic mases of Citrus sinensis cv. Pera were exposed to gamma irradiation at the dose 0–160 Gy and 0–189 Gy respectively, normal growth of plantlets was obtained from irradiated nucellus exposed to 20 – 80 Gy (Froneman, 1996).

Physiological changes in crop

Gamma irradiation induced physiological changes in crop although, gamma radiation is a technology with immense applications in agriculture, industry and medicine, its potential exploitation in agriculture is limited mainly because of lack of information awareness on optimal dose of irradiation which differs from one crop to another crop and from one application to another application. Radiation mediated morphological, structural and/or functional changes in a plant are governed by the intensity and duration of the gamma irradiation. In wheat, particularly, research efforts are needed to develop plant types with reduced height, which would enable them to tolerate gusty wind and contain losses due to lodging and subsequently grain yield. Mashev et al. (1995) used high irradiation dose of 5000–15 000 R to achieve a decrease in plant height and an increase in yield and suggested that even higher irradiation dose could be used to develop yield efficient wheat plant types. Wheat grains from irradiated plants were also rich in proteins and essential amino acids (Mashev et al., 1995). Din et al. (2003) studied the effect of gamma irradiation on different wheat varieties at seed irradiation dose of 10, 20, 30 and 35 krad. A higher dose of 30 and 35 krad created some abnormalities in plant types for example, a tiller having two ears attached with each and/or prevalence of sterile ears etc. Mashev et al. (1995), observed a significant decline in grain yield of wheat at doses above 0.10 kGy, however, lower doses of 0.01 and 0.025 kGy increased grain yields. Spielmeyer et al. (2007) had used a high vigour breeding line vigour 18 to identify a QTL on chromosome 6A that accounted for up to 8% of the variation for coleoptile length, 14% of seedling leaf width and was associated with increased plant height. They found a SSR marker, NW 3106, nearest to the 6A QTL that was associated with greater leaf width in a breeding population. The Vigour 18 allele of the QTL on chromosome 6A promoted coleoptile length and leaf width not only during early plant growth but was also found to be associated with increased plant height at maturity (Spielmeyer et al., 2007).

Biochemical change in crop

Extensive research showed that the macronutrients (carbohydrates, proteins and lipids) content are relatively stable against irradiation doses up to 10 kGy (WHO, 1994). However, Lee et al. (2005) reported that gamma irradiation affects proteins by causing conformational changes, oxidation of amino acids, rupturing of covalent bonds and formation of protein free radicals. Also, chemical changes in the proteins caused by gamma irradiation include fragmentation, cross-linking, aggregation and oxidation by oxygen radicals that are generated in the radiolysis of water. Gamma irradiation has a slight effect on the amino acid profile at recommended doses to foods (WHO, 1999). This effect could be related to the structure of each amino acid as revealed by many authors (Simic, 1983; Urbain, 1986; Elias and Cohen, 1997; Matloubi et al., 2004; Erkan and Ozden, 2007). The previous authors concluded that simple amino acids increased upon irradiation, such as glycine, which undergo reductive deamination and decarboxylation. In addition, aliphatic amino acids with increasing chain length, provide additional C–H bonds for interaction with OH radicals which reduces the extent of oxidative deamination. Wang and von Sonntage (1991) reported that sulfur containing as well as aromatic amino acids are, in general, the most sensitive to irradiation, while simple amino acids could be formed by destruction of other amino acids. Diehl (1995) and Matloubi et al. (2004) reported that there is a mutual protection exerted when different substances are irradiated together.

The results of irradiating multiple compounds together will, generally, not cause much chemical change in any one of the compounds, when irradiated alone. The effects of gamma irradiation on physicochemical changes in proteins have been described in previous studies, where chemical trans-formations of amino acids, breakdown of peptide bonds, hydrogen and disulphide bridges were observed (Ambe et al., 1961; Bernofsky et al., 1959; Nisizawa, 1988; Puchala et al., 1979; Zabielski et al., 1984).

Delincee and Pushpa (1981) observed cross-linking of the chain influences of the tertiary structure of proteins and their physicochemical properties. Decomposition and denaturation were detected in irradiated proteins (Ciesla et al., 2000). The decrease of apparent amylose content was possibly originated from the breakage or cleavage of long chains in amylopectin caused by gamma irradiation (Wu et al., 2002). It also agreed with Descherider and Grant's observation (Descherider, 1960; Grant and D'Apponlonia, 1991) that the decreasing apparent amylose content results from the shortening of polysaccharide chains. Ciesla et al. (2000), stated that indicating modification of proteins occurring after gamma irradiation similar to the transformations taking place under heating.

Kanemaru, et al. (2005), reported that protein content for the irradiated semolina and semolina obtained from irradiated wheat grains was not affected with gamma irradiation and ranged around 10.6-10.9%. Similarly, these results also agreed with the findings of Marathe et al. (2002), Agundez-Arvizu et al. (2006) and Azzeh and Amr (2009). Kwon et al. (1988) concluded from their studies on a Korean garlic cultivar that immediately after gamma irradiation with 100 Gy there are no differences in the levels of linoleic, palmitic, oleic and linolenic acids, the predominant fatty acids of bulbs.

The low radiation dose used could have produced its long-term effects in part by means of the stimulation of lipid degradation, possibly mediated through the action of free radicals that are known to be generated after irradiation (Katsaras et al., 1986; Voisine et al., 1991). In plant tissues subject to different forms of stress, polar lipids are degraded to generate free fatty acids and diacylglycerols, resulting in an eventual accumulation of TG as a defense mechanism (Olsson, 1995; Navari-Izzo et al., 1990).

Effect of irradiation on crop growth and seed germination

When ionizing radiation is absorbed in biological materials, it acts directly on critical cell targets or indirectly through the generation of metabolites that can modify important cell components. Low doses of gamma irradiation have been used to advantage in order to control the degree of ripeness and extend the shelf life of fruits and vegetables. The use of ionizing radiation depends on a country as food irradiation is illegal in some countries. Detection methods of ionizing radiation are also required for enforcing good control. Methods such as inhibition of seed germination and elongation of roots and shoots from germinating seeds have been reported for the detection of irradiated seeds of crop species (Qiongying et al., 1993; Zhu et al., 1993; Selvan and Thomas, 1999; Barros et al., 2000). Chaudhuri (2002) reported a simple and reliable method to detect gamma irradiated lentil seeds by germination efficiency and seedling growth test.

There is a difference in the detection of irradiated seeds of kabuli -type chickpeas and wild Cicer species. Toker and Cagirgan (2004) reported that the shoot length of kabulitype chickpeas was induced by 100Gy irradiation as compared to the controls. For this reason, only 200, 300 and 400 Gy doses were taken into account for irradiation. Chaudhuri (2002) found similar results with lentil. Villavicencio et al. (1998) showed that root growth and the almost totally retarded shoot elongation of irradiated common bean and mung bean were markedly reduced as compared to the non-irradiated checks. They stated that the critical dose that prevented shoot and root elongation varied among species and also ranged from genotype to genotype within species. The kabuli types were more affected than the desi ones. This is a certain and reliable way to identify the effects of gamma rays on Cicer seeds in a very short time. These effects might in time be developed into a method for irradiation detection. Higher doses inhibit germination.

Chromatographic analysis of some herbal extracts indicated that changes in total yield and constituents of volatile oil following irradiation were ranged from none to slight depending upon dose-based irradiation in variety of herbs (IAEA, 1992; Venskutonis et al., 1996; Chatterjee et al., 2000). It can be assumed, therefore, that the dose which can be applied and hence extent to the microbial kill may be limited by undesirable changes in volatile oil constituents, their yield and flavor quality. Farag et al. (1995) that reported terpenes were converted to monoterpe-nesalcohols. b-Eudesmol, an oxygenated monoterpenes, was the major compound in this group, while verbenol, a-eudesmol, verbenone, and (E)-r-2-menthen-1-ol were also detected. The a-and b-eudesmol were increased to 9.52% from 6.91%, with no major variation between the different irradiation doses. The remaining oxygenated terpene levels also did not vary significantly during irradiation. Quantity of paeoniflorin in Paeoniae radix, i.e. no change with irradiation as cited by Yu et al. (2004). In addition, Owczarczyk et al. (2000) have reported that the content of biologically active substances, including the essential oils, flavonoids, glycosides, anthocyanins, and plants mucus did not change significantly after irradiation. Irradiation can also increase the alkaloids percentage in the different organs of plant, particularly the leaves (Abo Elseud, 1983; El-Kholy, 1987; Habba, 1989). The increase or decrease in the germination percentage was found to attributed to gamma rays treatments. The stimulating effects of gamma ray on germination may be attributed to the activation of RNA synthesis (Kuzin at al., 1975) on coster bean, or protein synthesis (Kuzin et al., 1976) which occurred during the early stage of germination after seeds irradiated with 4 K-rad. These results are in agreement with the findings of Grover and Dhanju, (1980) on *Papaver somniferum* and Donge et al. (1986) on tea seeds. Habba (1989) who reported that increasing the dose of gamma rays up to 100 Gy, gradually increased the germination percentage, and then decreased gradually with increasing the gamma ray dose in the second season in *Hyoscyamus muticus*. Hell et al., (1974) stated that on *Phaseolus vulgaris*, treating seeds with high rates of gamma radiation reduced germination. Abo Elsauod and Omran (1976) indicated that irradiation snap bean seeds with 50, 100 and 150 Gy resulted in greater percentage of germination than the control. Regarding the effect of GA on seed germination an increase in germination percentage was observed by 3 increasing GA concentration was in confirmity with Ruminska et al. (1978) Who reported that the seed 3 soaking, preceding the sowing, in solutions 500, 1000, 1500 and 2000 ppm of GA improved germination ability of seven species of seeds, particularly good effects were achieved with *Lavandula vera* and *Atropa belladonna* where not only germination ability was not only increased but also accelerated and even shooting was obtained. Increase in higher germination percentage at higher doses might be due to their stimulating effects on activating RNA synthesis or protein synthesis (Kuzin et al., 1975; 1976) or it could be due to the elimination of germinating bacterial populations, their spores and mould fungi (Gruner et al., 1992)

Food irradiation

Research on food irradiation dates back to the turn of the twentieth century with the first United States of America and British patents being issued in 1905. It allowed the use of ionising radiation to kill bacteria in food (ICGFI 1999). The United States have since amended their drug regulations to allow the irradiation of certain food products to control food-borne pathogens (USEPA 2002). Food irradiation is a process in which products are exposed to ionizing energy, such as gamma rays, electron beams and X-rays for a specified time (FDA, 1986). A food is irradiated to utilize the destructive power of ionization radiation on the microorganisms with minimum changes in food constituents (Zenthen and Sorensen, 2003). Nowadays, irradiation of food is permitted in over than 60 countries for the purpose of food preservation by destruction of microbes, worms, insects and parasites, as well as for the inhibition of sprouting of potatoes and onions (IAEA, 2007). According to international health and safety authorities; Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Foods (JECFI), foods irradiated up to 10 kGy are considered safe and present no toxicological hazard and no special nutritional or microbiological problems in food (Anonymous, 1981). Gamma radiation of 30–1000 Gy has been applied to achieve a delay in the ripening of some fruits and vegetables (WHO 1988). A reduction in the amount of visible and total mould present in bread during a storage period of up to 20 weeks was reportedly achieved by applying a gamma radiation dose of 150 Gy to the flour (Adejumo 1998). Bansa and Appiah (2003) have also reported the successful use of gamma radiation dose of 120 Gy to effectively inhibit sprouting in yams for six months under tropical ambient conditions. Furthermore, higher gamma radiation doses of 2–4 kGy have been used to successfully reduce the infection rate in sugar beet seeds (Rizk and Moussa 2003)while a dose of approximately 500 Gy has been employed to disinfect and also reduce microbial populations in cocoa beans (Adesuyi 1996).

Foods sterilized

During the last decade interest has increased in the methods of food sterilization and modification applying medium (1–10 kGy) and high doses (10–70 kGy) of irradiation as well as radiation processing of industrial products that contain starch. Foods sterilized at high doses may be consumed by immunologically depressed patients and can be stored at room temperature (for example bakery products, readily prepared meals). Radiation modification enables, moreover, removal of ant nutritional factors and inhibition of food allergies Doses of several dozen kGy are used for sterilization of pharmaceuticals and medical devices and for starch modification. Accordingly, it appears desirable to acquire knowledge about the functional and structural properties of foods and starch alone irradiated using medium and high doses and in the development of appropriate physicochemical testing methods.

CONCLUSION

Many investigate on effect of gamma radiation on crop were carried out and their results showed usage of gamma radiation have different effect on crop such as Biochemical and physiological change, growth and germination inhibition. Inhibition of seed germination and elongation of roots and shoots from germinating seeds have been reported for the detection of irradiated seeds of crop species. Gamma irradiation affects proteins by causing conformational changes, oxidation of amino acids, rupturing of covalent bonds and formation of protein free radicals. Also, chemical changes in the proteins caused by gamma irradiation include fragmentation, cross-linking, aggregation and oxidation by oxygen radicals that are generated in the radiolysis of water. Irradiation is effective method for microbiological decontamination of them, and the content of essential biologically active substances and pharmacological activity of medicinal herbs not change significantly with irradiation.

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