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Elicitation of luteolin by Gamma Radiation

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ABSTRACT

Mutagenesis by means of gamma rays has played an important role in producing new mutants with improved properties which can produce higher amounts of commercially important metabolites. *Cajanus cajan* when subjected to absorbed doses 0Gy, 30Gy, 50Gy, 100Gy, 150Gy and 200Gy showed a significant ($p<0.05$) differences in total luteolin content between treatments and control following variable doses of gamma radiation under both *in vivo* studies and *in vitro* studies. Maximmun content of luteolin (1.909mg/gm dry wt.) was found to be in the regenerative calli irradiated with absorbed dose 150Gy, where as 0.669mg/gm dry wt. was found in leaves irradiated with 150Gy grown under *in vitro* conditions. Minimum content of luteolin (0.319 mg/gm dry wt) was found in leaves irradiated with 30Gy grown under field conditions. Conclusively, thus it appears from the present observation that some of the cultures of *C. cajan* are tolerant to gamma irradiation and over produce luteolin. Elicitation of secondary metabolites has applications in over production of desired compounds, which is an area of commercial importance especially for high value low volume products.

Key words: *Cajanus cajan* , Gamma rays , Luteolin, *In-vitro,* Regenerative calli

INTRODUCTION

Nuclear techniques have approached the world scene with the corporate mission of using atomic energy for peace, health and prosperity including sustainable agricultural development and improved food security. The most vital benefit that atomic energy can bring to agriculture is an increase in crop yields by producing new varieties of plants through radiation induced genetic changes or by directly stimulating growth. Prime among these atomic energy sources are gamma rays. γ rays are the most energetic form of electromagnetic radiation , and possess an energy level from 10 keV (kilo electron volts) to several hundred keV , and they are considered as the most penetrating radiation source compared to other sources such as alpha and beta rays (Kovacs and Keresztes, 2002).

Mutation induction with radiation is most frequently used method to develop direct mutant varieties, as improvement with limited genetic variation [Elliot,2004], [Yaqoob, 2001]. Mutagenesis by means of gamma rays has played an important role in the producing new mutants with improved properties which can produce higher amounts of commercially important metabolites [Sanada, 1986]. Concerning the effect of γ –irradiation on phenolic compounds different results were reported. The differences were mainly due to the species of the plant and the dose applied. The irradiation of traditional medicines and herbal products does not result in any negative chemical changes or important losses of active components[Soriani, 2005],[Mishra, 2007],[Lee,2005]. The increase in extraction yields with radiation treatment has also been reported by Haung and Mau (2007)], Variyar, Bandyopadhay , and Thomas (1998) found increased amount of phenolic acids in irradiated cloves and nutmeg. Effect of γ-irradiation at 10kGy on the free radical and antioxidants contents in nine aromatic herbs and spices (basil, bired pepper, black pepper, cinnamon, nutmeg, oregano, parsley, rosemary and sage) were studied by Calucci *et al* ., (2003) . Various studies on effects of γ irradiation on active principles in plants are summarized in (Table I).

Cajanus cajan L. is a perennial member of the family Fabaceae, used in the treatment of kidney ailments, hepatitis, measles, sickle cell anemia, abdominal tumors, diabetes and traumatism. It is also used as an anti-inflammatory and antibiotic effects as well as a sedative drug. In China, *Cajanus cajan* is considered as an excellent "Traditional Chinese Medicine" for therapy of ischemic necrosis of femoral head. It also contains some polyphenols, especially flavonoids known for their pharmacological applications used for the treatment of various human ailments. Its luteolin (LU) content is higher than those of other flavonoids. LU exhibits notable pharmacological effects.

Luteolin is one of the most common flavonoids present in edible plants and in plants used in traditional medicine to treat a wide variety of pathologies. Luteolin has also shown anti-allergic activity and in protecting plants against ultraviolet radiation. The antioxidant activity of luteolin has not only been observed *in vitro* but also *in vivo* [Quisheng, 2005],[Shimoi, 1994]. Several works have shown that luteolin, its glycosides or plants containing these flavonoids exert radioprotective and anticancer effects [Nayak, 2005],[Shimoi, 1996],[Vrinda, 2001],[Uma, 2001],[Devi, 1998],[Morquio, 2005]. Elangovan *et al*., 2004 observed that diets containing 1% luteolin reduced the incidence of fibrosarcoma in mice induced by subcutaneous injection of 20- methylcholanthrene. This flavonoid reduced the elevated levels of lipid peroxides and cytochrome P450 as well as the reduced activity of gluthathione-S-transferase induced by 20- methylcholanthrene

Till date there is no report asserting the use of gamma radiation as a physical elicitor to alter the phytochemical activity of luteolin in *Cajanus cajan.* Thus the aim of the present investigation conducted was to embark upon this issue by performing the phytochemical studies of luteolin in *Cajanus cajan* after exposures of pre-sowing (seeds) to variable doses of gamma rays under *in vivo* & *in vitro* conditions.

MATERIALS AND METHODS

Cajanus cajan L. was selected for the present study. The seeds were irradiated with gamma radiation of absorbed doses 0Gy, 30Gy, 50Gy, 100Gy, 150Gy and 200Gy for *in vivo* & *in vitro* studies. The device used was Gamma Cell GC-5000 BRIT–BOMBAY. The source of gamma radiation was Cobalt-60; with a dose rate 2.08 Kilo Gray per hour (2.08 KGh^{-1}) at Indian Institute of Nuclear Medicine and Applied Sciences (INMAS) New Delhi.

Extaction and quantification of luteolin:

Preparation of plant extracts sample solutions

The samples collected from *in-vivo* grown plant & *in-vitro* irradiated cultures were used for quantification of luteolin in different samples. The material was dried at 50°C in an air dryer for 48 h. Dried material was powdered by a disintegrator and then sieved (20-40 mesh). 5g pigeon pea leaves powder was extracted with 100ml of ethanol-water (80:20, v/v) solution in an ultrasonic bath for 15 min, repeated three times. The extracted solutions were combined and centrifuged at 6000 rpm for 10 min using a centrifuge. The supernatant extracts were concentrated to dryness by removing the ethanol solvent in a rotary evaporator at 55 °C, and *Cajanus cajan* extracts residue was obtained. All solutions prepared for HPLC were filtered through 0.45μm nylon membranes before used.

HPLC analysis of Luteolin

The HPLC analysis was carried out on a Waters liquid chromatographic system (Waters Company, USA) consisted of Millennium32 system software, Model Waters Delta 600 pump, and Model Waters 2996 Photodiode Array Detector (PAD). Chromatographic separation was carried out by HIQ sil C18V reversed-phase column (4.6 mmΦ×250 mm, KYA TECH Corporation, Japan) packed with 5 μm diameter particles, the mobile phase was acetonitrile-water-acetic acid (30:69.3:0.7, v/v/v). The mobile phase was filtered through a 0.45 μm membrane filter (Millipore, USA), and then deaerated ultrasonically prior to use. LU was quantified by a PAD at 347 nm following RP-HPLC separation. The flow rate was 1 ml/min, the injection volume was 25 μl, the column temperature was maintained at 30 °C, and the retention time of LU was 12.1 min. The chromatographic peak of the LU was confirmed by comparing its retention time and UV spectrum with that of the reference standard. The working calibration curve based on LU standard solutions showed good linearity over the range of 0.5-100 μg/ml. The regression line was $Y = 117890X - 18301$($R^2 = 0.9997$, $n = 8$), where Y is the peak area of LU and X is the concentration of LU (μg/ml).

Statistical Analysis

Each experiment was performed three times and all the determinations obtained from three replicates (N=3). The data values were submitted for analysis of variance for each factor (dose and developmental stages) and their interaction. One-way analysis-ANNOVA (HSD, $P \leq 0.05$) test (GraphPad Prism 5, 2003 Analytical Software) was used.

RESULTS

Isolation of Luteolin by HPLC Method

Comparing the integration peaks, there was significant differences in total luteolin content between treatments and control following variable doses of gamma radiation under both *in vivo* studies and *in vitro* studies (Fig1). Overall, gamma irradiation effectively increased the luteolin content in *Cajanus cajan*. Differences in the relative content of luteolin between the control and gamma radiation, treatments were significant ($p<0.05$). However, there are differences in the yields of luteolin.

Maximum accumulation of luteolin was observed with absorbed doses 100Gy and 150Gy. Maximmun content of luteolin (1.909mg/gm dry wt.) [Fig.1] was found to be in the regenerative calli irradiated with absorbed dose 150Gy, where as 0.669mg/gm dry wt. was found in leaves irradiated with 150Gy grown under *in vitro* conditions [FIG.2]. Minimum content of luteolin (0.319 mg/gm dry wt) was found in leaves irradiated with 30Gy grown under field conditions.

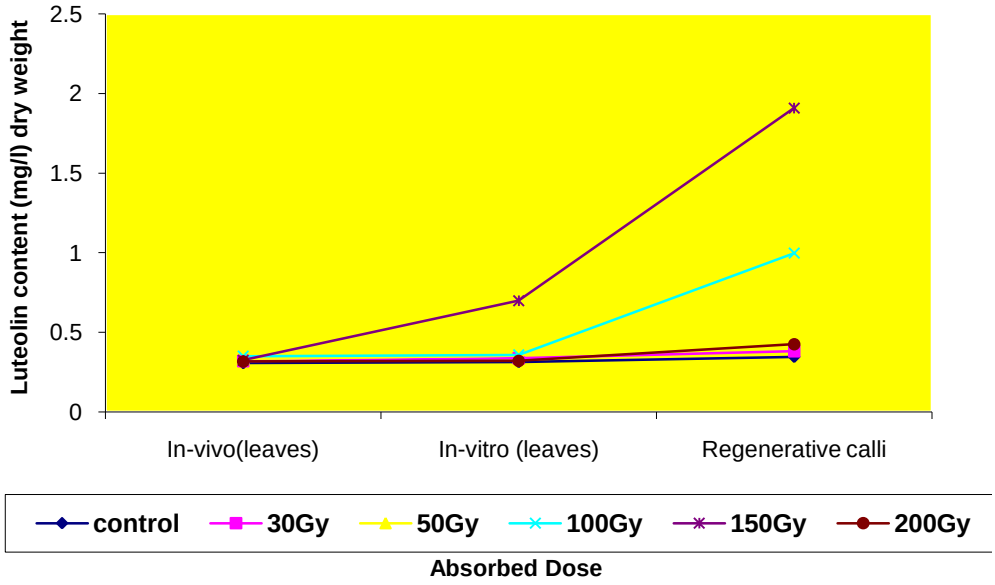


Fig1: Variation in luteolin content (mg/gm dry wt.) in various samples treated with doses of gamma radiation.

DISCUSSION

Active metabolite content:

During the 80-ies the influence of gamma irradiation on different properties of some pharmaceutical plants was investigated by various authors [Aladjadiyan,2007],[Aladjadiyan, 1997], [Aladijiyan, 2003],[Selenia, 1979],[Youssef, 1998], [Deaf, 2000],[Mahmoud, 2002],[Zheljazkov, 1996]. Pre- sowing irradiation is one of the most effective methods to improve plant production, yield components and chemical composition [Khan, 1970],[Youssef, 1998]. Luteolin is one of the most common flavonoids present in edible plants and in plants used in traditional medicine to treat a wide variety of pathologies. The antioxidant activity of luteolin and its glycosides has been associated with their capacity to scavenge reactive oxygen and nitrogen species[Kio, 1998],[Cai, 1997],[Horvathova, 2005],[Odontuya, 2005]. Lemanska, *et al* ., 2004 to chelate transition metals that may induce oxidative damage through the Fenton reaction [Mira, 2002],[Cheng, 2000] to inhibit prooxidant enzymes [Hu C, 2004],[Kong, 1999],[Nagao,1999],[Sadik, 2003] to induce antioxidant enzymes [Chai.BM, 2008],[Lim. JH, 2007],[Wruck, 2007]. The antioxidant activity of luteolin has not only been observed *in vitro* but also *in vivo*[Quisheng, 2005], [Shimoi, 1994], [Kim. JH, 2004].

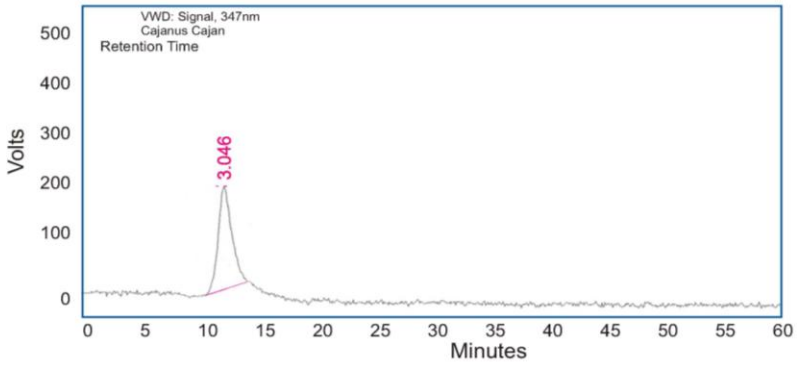
Flavonoids are known to have anti-inflammatory properties [Kim. JH, 2004]. Numerous papers have reported that luteolin, its glycosides, or plants containing luteolin have antiviral [Tshikalange. TE, 2005],[Yi. L, 2004], [Liu. AL, 2008] and antifungal activity.[De Campos MP,2005], [Sartori. MR, 2003].

Several *in vivo* studies suggest that luteolin has cancer chemopreventive potential. Elangovan *et al*., 2004 observed that diets containing 1% luteolin reduced the incidence of fibrosarcoma in mice induced by subcutaneous injection of 20-methylcholanthrene. This flavonoid reduced the elevated levels of lipid peroxides and cytochrome P450 as well as the reduced activity of gluthathione-S-transferase induced by 20- methylcholanthrene. It is accepted that flavonoids such as luteolin play an important role in protecting plants against ultraviolet radiation [Harborne ,2000],[Antogoni, 2007]. Several works have shown that luteolin, its glycosides or plants containing these flavonoids exert radioprotective effects *in vitro* [Nayak, 2005],[Shimoi, 1996],[Vrinda, 2001],[Uma, 2001],[Devi, 1998],[Morquio, 2005].

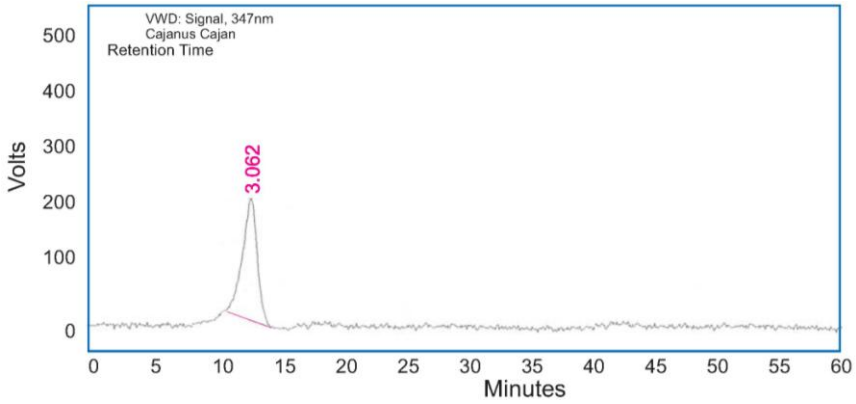
The increase in the quantity of some constituents as affected by gamma irradiation may be attributed to the fact that some natural chemical constituents are released from their precursors due to degradation resulting from irradiation. Harison and Were (2007)and Adamo *et al.*, 2004 reported that phenols are increased by gamma irradiation due to the release of phenolic compounds from glycosidic components and the degradation of polyphenolic compounds into soluble phenols as well as other small metabolites The ability of gamma irradiation to increase polyphenolic acids in plant material has also been observed in soybeans. Soybean samples treated with gamma irradiation at levels ranging from 50 to 150Gy had increased free polyphenolic acids [Variyar . PS, 2004], Siddhuraju *et al.*,(2002) attributed such increase in polyphenolic acids to higher extractability by depolymerization and dissolution of cell wall polysaccharides due to gamma irradiation. Moreover, gamma irradiation was known to increase the activity of phenylalanine ammonia lyase, which is responsible for the synthesis of polyphenolic acids [Sidduraju P, 2002].

In the present study, comparing the integration peaks, there was a significant difference in total luteolin content between treatments and control following variable doses of gamma radiation under both in-vivo studies and in-vitro studies(Fig.1) . Overall, gamma irradiation effectively increased the luteolin content in *cajanus cajan*. .Maximmun increment was recorded in the regenerative calli irradiated with absorbed dose 150Gy(Fig.2).

30 Gy (leaves in-vivo grown)



150Gy (leaves in-vitro grown)



150Gy (regenerative calli)

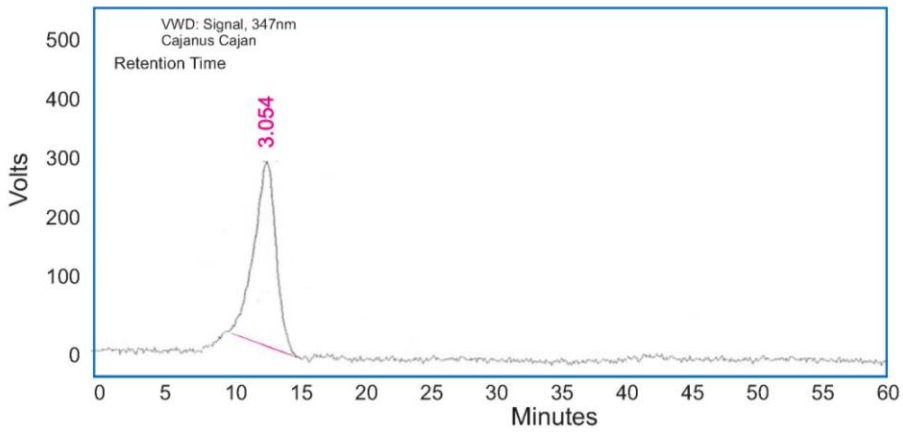


Fig2: HPLC profile of different samples of *Cajanus cajan* grown under *in vivo* & *in vitro* conditions treated with different absorbed dose of gamma radiation.

The increase in extraction yields with radiation treatment has also been reported by haung and Mau (2007).Similarly, Kim, yook, and Byun (2000) found an in increase in the extraction yields after treating medicinal herbs with gamma irradiation. There is no information available in the literature on the effect of ionizing radiation on the phenolic content of *cajanus cajan* .

Variyar, Bandyopadhay, and Thomas (1998) found increased amount of phenolic acids in irradiated cloves and nutmeg. Harison and Were (2007) also reported increase in total phenolic content of gamma – irradiated almond skin extract , as compared to control samples. Similarly, Huang and Mau (2006) reported a higher content of tocopherols in irradiated than control samples.

CONCLUSION

Conclusively, the results obtained from the present study prompted us to speculate that *Cajanus cajan* seeds exposed to variable doses of gamma radiation showed persistence changes in the luteolin content under both *in vivo* & *in vitro* conditions. Cultured cells and tissues have been found to accumulate secondary metabolites in excess compared to grown in natural environment. In our studies, *in vitro* grown cultures produced more luteolin than field grown plant. Among various gamma radiation doses, maximum luteolin was found in 12 weeks old regenerative callus at 150Gy absorbed dose. Thus it appears from the present observation that some of the cultures of *C. cajan* are tolerant to gamma irradiation and over produce luteolin. Elicitation of secondary metabolites has applications in over production of desired compounds, which is an area of commercial importance especially for high value low volume products. Agrobacterium mediated transformation of DNA and similar type of biotechnological approaches may be useful in future to produce transformed variety producing maximum yield of secondary metabolites.

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Declaration of interest The authors report no declarations of interest.

REFERENCES

[1]. Antognoni F, Zheng S, Pagnucco C, Baraldi R, Poli F, Biondi S. (2007). Induction of flavonoid production by UV-B radiation in Passiflora quadrangularis callus cultures. *Fitoterapia*, 78, 345-52.

[2]. Adamo M, Capitani D, Mannina L, Cristinzio M, Ragani P, Tata A, Coppola R. (2004). Truffles decontamination treatment by ionizing radiation. *Rad. Phys. Chem*, 71,165-168.

[3]. Abdel-Hady M.S, Okasha EM, Soliman SSA, Talaat Me. (2008). Effect of gamma radiation and gibberellic acid on germination and alkaloid production in Atropa belladonna L. *Austra j bas App Scie,* 2(3) , 401-405.
[4]. Aladjadjiyan A. (2007). The use of physical methods for plant growing stimulation in Bulgaria. *J Cent Europ Agric* , 8 (3), 369-380.
[5]. Aladjadjian A, Svetleva D. (1997). Influence of magnetron irradiation on common bean (Phaseolus vulgaris L.) Seeds. *Bulg J Agr Science*, 3,741-747.
[6]. Aladjadjiyan A, Ylieva T. (2003)**.** Influence of stationary magnetic field on early stages of the development of tobacco seeds (*Nicotina tabacum*). *J Cent Europ Agric,* 4, 132-138.
[7]. Calucci L , Pinzion C, Zandmeneghi M, Capocchi A, Ghiringhelti S, Tozzi S, Galleschi L. (2003). Effect of γ-irradiation on the free radical and antioxidant contents in nine aromatic herbs and spices. *J Agric Food Chem* ,51(4), 927-934.
[8]. Cai Q, Rahn RO, Zhang R. (1997). Dietary flavonoids, quercetin, luteolin and genistein, reduce oxidative DNA damage and lipid peroxidation and quench free radicals. *Cancer Lett, 119*, 99-107.
[9]. Cheng IF and Breen K. (2000). On the ability of four flavonoids, baicilein, luteolin, naringenin, and quercetin, to suppress the Fenton reaction of the iron-ATP complex. *Biometals,* 13, 77-83.
[10]. Choi BM, Lim DW, Lee JA, Gao SS, Kwon DY, Kim BR. (2008). Luteolin suppresses Cisplatin-induced apoptosis in auditory cells: possible mediation through induction of heme oxygenase-1 expression. *J Med Food*, 11, 230-6.
[11]. Devi PU, Bisht KS, Vinitha M. (1998). A comparative study of radioprotection by Ocimum flavonoids and synthetic aminothiol protectors in the mouse. *Br J Radiol*, 71, 782-4.
[12]. Deaf NSD. (2000). Chemical and biological studies on some wild plants. M.Sc. *Thesis, Fac. Agric., Zagazig Univ., Zagagzig Univ., Zagazig, Egypt.*
[13]. De Campos MP, Cechinel FV , Da Silva RZ , Yunes RA, Zacchino S, Juarez S, Bella Cruz RC, Bella CA. (2005). Evaluation of antifungal activity of Piper solmsianum C. DC. var. solmsianum (Piperaceae). *Biol Pharm Bull*, 28, 1527-30.
[14]. Elangovan V, Sekar N, Govindasamy S. (1994). Chemopreventive potential of dietary bioflavonoids against 20-methylcholanthreneinduced tumorigenesis. *Cancer Lett*, 87, 107-13.
[15]. Elliott et al. (2004). Efficient procedures for callus induction and adventitious shoot organogenesis in sugar beet (Beta vulgaris L) breeding lines. *In vitro Cell Dev Biol Plant, 40, 475-481.*
[16]. Harborne JB and Williams CA. (2000). Advances in flavonoid research since 1992. *Phytochemistry,* 55, 481-504
[17]. Harrison K, Were LM. (2007). Effect of gamma irradiation on total phenolic content yield and antioxidant capacity of Almond skin extracts. *Food Chemistry* ,102, 932–937.
[18]. Horvathova K, Chalupa I, Sebova L, Tothova D, Vachalkova A. **(**2005). Protective effect of quercetin and luteolin in human melanoma HMB-2 cells. *Mutat Res*, 565, 105-12.
[19]. Hu C and Kitts DD. (2004). Luteolin and luteolin-7-O-glucoside from dandelion flower suppress iNOS and COX-2 in RAW264.7 cells. *Mo Cell Biochem, 265*, 107-13.
[20]. Huang SJ, & Mau JL. (2006). Antioxidant properties of methanolic extracts from Agaricus blazei with various doses of c-irradiation. *LWT-Food Science and Technology*, 39, 707–716.
[21]. Huang SJ, Mau JL. (2007). Antioxidant properties of methanolic extract from Antrodia camphorate with various doses of γ-radiation. *Food Chemistry*, 105,1702–1710.
[22]. Kovacs E , Kereszetes A. (2002). Effect of gamma and UV/c radiation on plant cells. *Micr,* 33, 199-210.
[23]. Kiong ALP, Lai GA, Hussein S, Harun AR. (2008). Physiological responses of Orthosiphon stamineus plantles to gamma irradiation. *Ame-Eur J Sus Agric,* 2 (2), 135-149.
[24]. Khattak KF, Simpson TJ, and Ihasnullah. (2008). Effect of gamma irradiation on the extraction yield, total phenolic content and free radical-scavenging activity of Nigella sativa seed. *Food Chem* ,110(4), 967–972.
[25]. Lemanska K, van der WH, Szymusiak H, Boersma MG, Gliszczynska-Swiglo A, Rietjens IM, Tyrakowska B. **(**2004). The effect of catechol O-methylation on radical scavenging characteristics of quercetin and luteolin--a mechanistic insight. *Free Radic Res, 38*, 639-47.
[26]. Lim JH, Park HS, Choi JK, Lee IS, Choi HJ. (2007). Isoorientin induces Nrf2 pathway-driven antioxidant response through phosphatidylinositol 3-kinase signaling. *Arch Pharm Res,* 30, 1590-8.
[27]. Liu AL, Liu B, Qin HL, Lee SM, Wang YT, Du GH. (2008). Anti-Influenza Virus Activities of Flavonoids from the Medicinal Plant Elsholtzia rugulosa. *Planta Med*, 74, 847-51.
[28]. Lee JH, Lee KT, Kim MR. (2005). Effect of γ-irradiated red pepper powder on the chemical and volatile characteristics of Kakdugi, a Korean traditional fermented radish kimchi. *J Food Sci,* 70 (7), 441-447.
[29]. Khan BM. (1970). Effect of gamma rays irradiation on yield and the incidence of blight disease of gram. *Agric J Pakistan*, 21, 43–6.
[30]. Kio FN, Chu CC, Lin CN, Chang CC, Teng CM. **(**1998). Isoorientin- 6"-O-glucoside, a water-soluble antioxidant isolated from Gentiana arisanensis. *Biochim Biophys Acta,* 1389, 81-90.

[31]. Kong LD, Wolfender JL, Cheng CH, Hostettmann K, Tan RX**.** (1999). Xanthine oxidase inhibitors from Brandisia hancei. *Planta Med,* 65, 744-6.
[32]. Kim JH, Baek MH, Chung BY, Wi SG, Kim JS. (2004). Alterations in the photosynthetic pigments and antioxidant machineries of red pepper (*Capsicum annuum* L.) seedlings from gamma-irradiated seeds. *J Plant Biotechnol,* 47(2), 314-321.
[33]. Kim MJ, Yook HS, Byun MW. (2000). Effects of gamma irradiation on microbial contamination and extraction yields of Korean medicinal herbs. *Radiation Physics and Chemistry,* 57, 55–58.
[34]. Musa HAA, Ahmed EEA, Osman GAM, Ali HA, and Müller JL. 2010. Microbial load and phytochemicals stability of camel hay (Cymbopogon schoenanthus L) leaves as affected by gamma irradiation. *Agric Biol J N Am,* 1(4), 662–670.
[35]. Morquio A, Rivera-Megret F, Dajas F. (2005). Photoprotection by topical application of Achyrocline satureioides ('Marcela'). *Phytother Res,* 19, 486-90.
[36]. Mishra M.N, Qadri H , Mishra S. (2007). Macro and micro mutations, in gamma-rays induced M_2 populations of Okra (Abelmoschus esculentus (L) Moench). INt. *J Plant Sci Muzaffarnagar,* 2 (1), 44-47.
[37]. Mira L, Fernandez MT, Santos M, Rocha R, Florencio MH, Jennings KR. **(**2002). Interactions of flavonoids with iron and copper ions: a mechanism for their antioxidant activity. *Free Radic Res,* 36, 1199-1208.
[38]. Mahmoud FAN. (2002). Effect of gamma radiation and some agrochemicals on germination, growth and flowering of *Delphinium ajacis* and *Mathiola incana* plants. *M.Sc. Thesis. Fac. Agric., Moshtohor, Zagazig Univ., Egypt*
[39]. Nagao A, Seki M, Kobayashi H. (1999). Inhibition of xanthine oxidase by flavonoids. *Biosci Biotechnol Biochem, 63,* 1787-90.
[40]. Nayak V, Devi PU. (2005). Protection of mouse bone marrow against radiation-induced chromosome damage and stem cell death by the ocimum flavonoids orientin and vicenin. *Radiat. Res,* 163, 165-71.
[41]. Odontuya G, Hoult JR, Houghton PJ. (2005). Structure-activity relationship for antiinflammatory effect of luteolin and its derived glycosides. *Phytother Res, 19,* 782-6.
[42]. Oufedjikh H, Mahrouz M, Amiot MJ, Lacroix M. (2000). Effect of γ-irradiation on phenolic compounds and phenylalanine ammonia-lyase activity during storage in relation to peel injury from peel of citrus dementina Hort. Ex. Tanaka. *J Agric*
[43]. Qiusheng Z, Yuntao Z, Rongliang Z, Dean G, Changling L. (2005). Effects of verbascoside and luteolin on oxidative damage in brain of heroin treated mice. *Pharmazie, 60,* 539-43.
[44]. Selenia LV, Stepanenko OG. (1979). Effect of pre–sowing gammairradiation on the productivity and active principle content of Matricaria recutita. *Rastitel'nye Ressusy,* 15, 143–54.
[45]. Seo H, Kim J, Kim D, Byun M , Kwon J, Kim K. (2007). Effects of γ irradiation on the yields of volatile extracts of Angelica gigas Nakai. *Rad Phys Chem,* 76,1869-1874.
[46]. Shimoi K, Masuda S, Furugori M, Esaki S, Kinae N. (1994). Radioprotective effect of antioxidative flavonoids in gamma-ray irradiated mice. *Carcinogenesis, 15,* 2669-72.
[47]. Shimoi K, Masuda S, Shen B, Furugori M , Kinae N. *(*1996). Radioprotective effects of antioxidative plant flavonoids in mice. *Mutat Res,* 350,153-61.
[48]. Sanada T. (1986). Induced mutation breeding in fruit trees resistant mutant to black spot disease of Japanese pear. *Gamma Field Symposia,* 25**(4),** 87-108.
[49]. Soriani, R.R., Satomi, L.C., de Jesus, T., Pinto, A. (2005). Effects of ionizing radiation in ginkgo and guard. *Ana. Rad Phys Chem,* 73(6), 239-242.
[50]. Sadik CD, Sies H, Schewe T. (2003). Inhibition of 15-lipoxygenases by flavonoids: structure-activity relations and mode of action. *Biochem Pharmacol,* 65, 773-81.
[51]. Sartori MR, Pretto JB, Cruz AB, Bresciani LF, Yunes RA, Sortino M, Zacchino SA, Cechinel VF. (2003). Antifungal activity of fractions and two pure compounds of flowers from Wedelia paludosa (Acmela brasiliensis) (Asteraceae). *Pharmazie,* 58, 567-9.
[52]. Siddhuraju P, Makkar HPS, Becker K. (2002). The effect of ionizing radiation on anti nutritional factors and the nutritional value of plant materials with reference to human and animal food. *Food Chem,* 78, 187-205.
[53]. Shikalange TE, Meyer JJ, Hussein AA. (2005). Antimicrobial activity, toxicity and the isolation of a bioactive compound from plants used to treat sexually transmitted diseases. *J Ethnopharmacol,* 96, 515-9.
[54]. Wruck CJ, Claussen M, Fuhrmann G, Romer L, Schulz A, Pufe T, Waetzig V, Peipp M, Herdegen T, Gotz ME. (2007). Luteolin protects rat PCl2 and C6 cells against MPP+ induced toxicity. *Suppl, **72,*** 57-67.
[55]. Uma DP, Ganasoundari A, Vrinda B, Srinivasan KK, Unnikrishnan MK. (2000). Radiation protection by the ocimum flavonoids orientin and vicenin: mechanisms of action. *Radiat Res,* 154, 455-60.
[56]. Variyar PS, Bandyopadhyay C, Thomas P. (1998). Effect of c-irradiation on the phenolic acid of some Indian spices. *International Journal of Food Science and Technology,* 33, 533–537.
[57]. Variyar PS, Limaye A, Sharma A. (2004). Radiation-Induced Enhancement of Antioxidant Contents of Soybean. *Journal of Agricultural Food Chemistry,* 52(6), 3385-3388.

[58]. Vrinda, B. and Uma, D.P. (2001). Radiation protection of human lymphocyte chromosomes *in vitro* by orientin and vicenin. *Mutat Res, 498*, 39-46.
[59]. Youssef AA, Moussa AZ. (1998). Effect of gamma rays on growth and essential oil composition of chamomile (*Chamomilla recutita* L.). *Arab Univ J Agric Sci*, 6, 301–11.
[60]. Yaqoob M, Rashid A. (2001). Induced mutation studies in some mungbean (Vigna radiata L.) Wilczek cultivars. *J Biol Sci*, 1, 805-808.
[61]. Yi L, Li Z, Yuan K, Qu X, Chen J, Wang G, Zhang H, Luo H, Zhu L, Jiang P, Chen L, Shen Y, Luo M, Zuo G, Hu J, Duan D, Nie Y, Shi X, Wang W, Han Y, Li T, Liu Y, Ding M, Deng H, Xu X. **(**2004). Small molecules blocking the entry of severe acute respiratory syndrome coronavirus into host cells. *J Virol, 78*, 11334-9.
[62]. Zheljazkov V, Margine A, Stovea T, Shetty K. (1996). Effect ofgamma irradiation on some quantitative characteristics in mint andcornmint. *Acta Hort,* 426, 381–84

Table. I Effects on gamma radiation on the metabolite content different species.

Dosage applied & duration of irradiations	Species	Plant part or age/ stage of plant growth for y-irradiation	Metabolites content/yield	References
1,3,5,10 and 20 kGy	Angelica gigas Nakai	Leaves	The major volatile compounds were identified 2,4,6-trimethyl heptanes, a-murrolene and sphatulenol, a-limonene, βudesmol, a-murrolene and sphatulenol. The irradiated samples at doses of 1,3,5,10 and 20 kGy were 8.82% and 82.58%, respectively	Seo et al., 2007[21]
2,4,8,10, 12 and 16 kGy 0.96 kGy/h	Kalungi (Nigella sativa)	Seeds	Extraction yields increases were 3.7%, 4.2%,5.6% and 9.0% for hexane, acetone, water and methanol extracts. Phenol content increased from 3.7 for control to 3.8mg/g for 16 kGy.	Khattak et al., 2008[22]
50,80,110 and 150 Gy. Dose rate 0.54 Gy/min	Atropa belladonna L.	Seeds	Seeds irradiated at 110 Gy possessed 4.01 mg/g and 109.67 mg/plant twice alkaloid value than control (2.03 mg/g and 53.41 mg/plant).	Abdel Hady et al., 2008[23]
2,4,8,10,12 and 16 kGy 0.96 kGy/h	Kalungi (Nigella sativa)	Seeds	Extraction yields increases were 3.7%, 4.2%,5.6% and 9.0% for hexane, acetone, water and methanol extracts. Phenol content increase from 3.7 for control to 3.8 mg/g fo r16 kGy.	Khattak et al., 2008[22]
0,10,20,30,40,50,60 and 70 Gy 4.64 kGy/h	Orthosiphon stamineus	Shoot tips	Rosamarinic acid content was lowest 5.27 mg/g fw in plantlets irradiated at 10kGy and highest 8.40 mg/g fw at 30 Gy.	Kiong et al., 2008[24]
50,80,110 and 150 Gy, dose rate 0.54 Gy/min	Atropa belladonna L.	Seeds	Seeds irradiated at 110 Gy possessed 4.01 mg/g and 109.67mg/plant twice alkaloid value than control (2.03 mg/g and 53.41 mg/plant).	Abdel Hady et al., 2008[23]
5,10, and 15 kGy, The activity of the source was 6.345 Kci and the energy 1.25 Mev	Camel hay(Cymbopogon schoenanthus)	Leaves	21% reduction in tannins as a result of gamma irradiation and phenol content by more than 25% at 15 kGy	Musa et al., 2010[25]