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Effects of irradiation on active components of medicinal plants: A review

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ABSTRACT

Contamination with microorganisms is one of the most serious problems of medicinal plants. The methods utilized to solve this problem are irradiation, heat and fumigation (ethylene oxide). Irradiation is an effective method to decontaminate medicinal plants, however, it may affect active components of the plants. Additionally, the heat generated during steam sterilization may also have affects on the active compounds in plants. This article reviews the effects of irradiation on active components and biological activities of medicinal plants. The information will be useful for future studies in decontamination protocols where biological activity must be preserved.

Keywords: *irradiation, antioxidants, active components, medicinal plants, herbs, volatile compounds*

1. Introduction

As the world demand for natural products has been increasing, using plants as medicine, cosmetics and food supplements has also been increasing. However, a serious problem with plants is microbial contamination which affects health and has economic impacts. Therefore, decontamination of plant materials is important to increase the safety of medicinal plants. Medicinal plants can be decontaminated using heat, fumigation (ethylene oxide; ETO) and irradiation. Heat is not suitable for heat sensitive products. ETO is prohibited in many countries such as Japan and some European countries because it reacts with organic components leaving harmful residues. (Chmielewski & Migdal, 2005). The sources for ionizing radiation used to decontaminate microorganisms are high-energy electrons (electron beam; E-beam), X-rays or gamma rays (γ-rays). The objective of this review is to summarize the effects of ionizing radiation on active components and biological activities of medicinal plants, covering the currently available literature between 1987 and 2011.

1.1 Radiations used to decontaminate microorganisms

1.1.1 Electron beam (E-beam)

The electrons used for medicinal plant irradiation are produced by an electron accelerator. The major advantage of using electrons is that the source for the electrons can be turned off when not in use. Treatment with electron beams can provide the highest throughput rates and lowest unit costs. However, the major limitation of electron beam is its low penetrating power, therefore it is unsuitable for thick products (IAEA, 2008).

1.1.2 X-rays

X-rays are electromagnetic radiation which have the same properties as gamma rays (see below). The major advantage of X-rays is similar to an E-beam; the source of X-irradiation can be turned on/off. The use of high energy X-rays for sterilizing medical products was proposed during the 1960s (IAEA, 2008).

1.1.3 Gamma rays

Gamma rays are a type of electromagnetic radiation which originates within the nucleus of a radioisotope. Irradiation facilities generally use the radionuclide cobalt-60, instead of cesium-137, as the source of gamma rays because it is easier to obtain, has a lower environmental risk and emits four times more energy per disintegration, respectively. The energy threshold for inducing radioactivity in herbs is 5 Mev for gamma sources (WHO, 1999). Therefore, the energy of gamma rays from cobalt-60 (1.17 Mev and 1.33 MeV) is not sufficient to generate radioactive substances in medicinal plants. Gamma irradiationhas been the most popular method used in commercial preparations for medicinal plants (Fang & Wu, 1998) due to its efficiency and high penetration. Additionally, it can be used for products in final packaging (IAEA, 2008).

1.1.4 Radiation doses

The amount of radiation energy that a material absorbs is measured in SI units called "gray (Gy)". One gray is equivalent to one joule per Kg (IAEA, 1990). The Gray replaced the earlier unit, the rad (1 Gy = 100 rad).

2. Reviewed results on the effect of irradiation on active components

Irradiation is utilized to inactivate microorganisms. The Joint Expert Committee on Food Irradiation (JECFI) convened by Food and Agriculture Organization (FAO), World Health Organization (WHO) and International Atomic Energy Agency (IAEA) evaluated available data and concluded that "the irradiation of any food commodity" up to an overall average dose of 10 kGy "presents no toxicological hazard" and requires no further testing (WHO, 1999). While deemed non-toxic irradiation may affect active compounds of the irradiated medicinal plants. The results on the effects of irradiation on active components are contradicting. Tables 1, 2 and 3 list the effects of irradiations on antioxidants, volatile compounds, and other active compounds and biological activities, respectively.

Table 1 Effects of irradiation on antioxidants

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
10 phytopreparations	E-beam/ 10	Flavonoids, anthocyanins and polyphenolic acids did not change significantly.	Owczarczyk, Migdal, and Kedzia (2000)
Anise (*Pimpinella anisum* L.) Cinnamon (*Cinnamomum verum* J. Presl) Ginger (*Zingiber officinale* Roscoe) Licorice (*Glycyrrhiza glabra* L.) Mint (*Mentha spicata* L.) Nutmeg (*Myristica fragrans* Houtt.) Vanilla (*Vanilla planifolia* Jacks. ex Andrews.)	E-beam/ 1-10	Irradiated samples did not show significant differences in the antioxidant activity with respect to the non-irradiated samples.	Murcia, Egea, Romojaro, Parras, Jimenez, and Martınez-Tome´ (2004)
Sea buckthorn (*Hippophae rhamnoides* L.)	E-beam/ 3-20	Irradiation with 20 kGy caused an important reduction in the content of carotenoids, polyphenolcarboxylic acids, flavonoids and antioxidant activity.	Minea, Nemtanu, Manea, and Mazilu (2007)
Satsuma Orange pomaces (*Citrus unshiu* Marcow.)	E-beam/ 3.6-37.9	Enhancement in the total phenolic contents.	Kim, Lee, B.C., Lee, J.H., Nam, and Lee, S.C (2008)

Table 1 Effects of irradiation on antioxidants (continued)

Medicinal plants	**Types of radiation/ irradiation doses (kGy)**	**Major findings**	**References**
Cinnamon (*Cinnamomum verum* J.Presl) Clove (*Syzygium aromaticum* (L.) Merr. & L.M. Perry) Cardamom (*Elettaria cardamomum* (L.) Maton) Nutmeg (*Myristica fragrans* Houtt.) Mace (*Myristica fragrans* Houtt.)	γ-rays/ 10	The **increase**s in phenolic contents were associated with the degradation of tannins.	Variyar, Bandyopadhyay, and Thomas (1998)
21 Korean medicinal herbs *Aconitum carmichaeli* Debeaux *Aconitum jaluense* Kom. *Agrimonia pilosa* Ledeb. *Alisma plantago* var. *Parviflorum* Torr. *Angelica gigas* Nakai *Astragalus membranaceus* (Fisch.) Bunge *Atractylodes japonica* Koidz. ex Kitam. *Curcuma zedoaria* (Christm.) Roscoe *Curcuma longa* L. *Ephedra sinica* Stapf *Ganoderma lucidum* (Fr.) Karst *Gingko biloba* L. *Gynura japonica* (Thunb.) Juel *Ligusticum jeholense* (Nakai & Kitag.) Nakai & Kitag. *Paeonia japonica* (Makino) Miyabe & H.Takeda *Panax ginseng* C.A.Mey. *Poria cocos* F.A. Wolf *Rehmannia glutinosa* (Gaertn.) DC. *Scirpus maritimus* L. *Scrophularia oldhamii* Oliv. *Scutellaria baikalensis* George	γ-rays/ 10	No significant effect on antioxidant, nitrite scavenging and electron donating ability.	Byun, Yooka, Kim, and Chung (1999)
Turmeric (*Curcuma longa* L.)	γ-rays/ 10	No effect on antioxidant activity.	Chatterjee, Desai, and Thomas (1999)
Rosemary (*Rosmarinus officinalis* L.) Watercress (*Nasturtium officinale* R.Br.) Artichoke (*Cynara scolymus* L.) Sweet basil (*Ocimum basilicum* L.)	γ-rays/ 10-30	No significant changes in flavonoids, tannins and phenolic contents.	Koseki, Villavicencio, Brito, Nahme, Sebastiao, and Rela (2002)

Table 1 Effects of irradiation on antioxidants (continued)

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
Bird pepper (*Capsicum frutescens* L.) Black pepper (*Piper nigrum* L.) Cinnamon (*Cinnamomum verum* J.Presl) Nutmeg (*Myristica fragrans* Houtt.) Oregano (*Origanum vulgare* L.) Basil (*Ocimum basilicum* L.) Sage (*Salvia officinalis* L.) Rosemary (*Rosmarinus officinalis* L.) Parsley (*Petroselinum sativum* Hoffm.)	γ-rays/ 10	Significant losses of total ascorbate in black pepper, cinnamon, nutmeg, oregano and sage; significant decrease of carotenoids in cinnamon, oregano, parsley, rosemary, bird pepper and sage.	Calucci, Pinzino, Zandomeneghi, Capocchi, Ghiringhelli, Saviozzi Tozzi, and Galleschi (2003)
Lupin seeds (*Lupinus angustifolius* L., *L. luteus* L., and *L. albus* L.)	γ-rays/ 1-10	Increasing doses of irradiation lowered antioxidant effects.	Lampart-Szczapa, Korczak, Nogala-Kalucka, and Zawirska-Wojtasiak (2003)
Soybean (*Glycine max* (L.) Merr.)	γ-rays/ 0.5-5	**Increase** of DPPH free radical-scavenging activity.	Variyar, Limaye, and Sharma (2004)
Ginkgo (*Ginkgo biloba* L.) Guarana (*Paullinia cupana* H.B.K.)	γ-rays/ 5.5-17.8	Flavonol glycosides in ginkgo and caffeine in guarana were not significantly different.	Soriani, Satomi, de Jesus, and Pinto (2005)
Black pepper (*Piper nigrum* L.)	γ-rays/ 5-30	The scavenging ability of DPPH radicals significantly decreased.	Suhaj, Rácová, Polovka, and Brezová (2006)
Velvet bean seeds (*Mucuna pruriens* (L.) DC.)	γ-rays/ 2.5-30	Enhancement in the total phenolic content.	Bhat, Sridhar, and Yokotani (2007)
Almond skin (*Prunus amygdalus* Stokes)	γ-rays/ 16.3	**Increase** in the yield of total phenolic content and antioxidant activity.	Harrison and Were (2007)
Oregano (*Origanum vulgare* L.)	γ-rays/ 30	Negligible effect on the DPPH radical-scavenging ability.	Horvathova, Suhaj, Polovka, Brezova, and Šimko (2007)
Rosemary (*Rosmarinus officinalis* L.)	γ-rays/ 30	Total phenolic content **increased** in the water extracts but remained the same in methanol and ethanol extracts. Radiation reduced the positive correlation between antioxidant activity and total phenolic content.	Perez, Calderon, and Croci (2007)

Table 1 Effects of irradiation on antioxidants (continued)

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
Soybean seeds (*Glycine max* (L.) Merr.) (genotype Ana)	γ-rays/ 1-10	**Increase** of total phenolic and antioxidant activity.	Štajner, Milošević, and Popović (2007)
Clove (*Syzygium aromaticum* (L.) Merr. & L.M. Perry) Ginger (*Zingiber officinale* Roscoe)	γ-rays/ 5-30	**Increase** in the contents of oxidative substances was proportional to the intensity of radiation.	Suhaj and Horvathova (2007)
Black cumin seeds (*Nigella sativa* L.)	γ-rays/ 2-16	**Increase** of extraction yield and total phenolic content, as well as enhancing the free radical-scavenging activity.	Khattak, Simpson, and Ihasnullah (2008)
Curcuma longa L. *Andrographis paniculata* (Burm.f.) Nees	γ-rays/ 10	No significant difference on the DPPH radical-scavenging ability.	Thongphasuk, P., Thongphasuk, J., Pongpat, Kuljanabhagavad, Iamsiri› and Sajjabut (2008)
Bark of cinnamon (*Cinnamomum verum* J.Presl) Leaves of sage (*Salvia officinalis* L.) Green tea (*Camellia sinensis* (L.) Kuntze)	X-rays	Considerable loses of total polyphenols and flavonoids.	Abdul Lateef and Al-Nimer (2009)
Red chillies (*Capsicum annuum* L.)	γ-rays/ 2-6	No significant effects on total phenolics.	Abrar, Anjum, Zahoor, and Nawaz (2009)
Leaves of green tea (*Camellia sinensis* (L.) Kuntze) Sage (*Salvia officinalis* L.) Bark of Cinnamon (*Cinnamomum verum* J.Presl) Root of Ginger (*Zingiber officinale* Roscoe)	X-rays	Loss of flavonoids and total polyphenols from irradiated ginger and cinnamon.	Al-Nimer Marwan and Abdul Lateef (2009)
Sage (*Salvia officinalis* L.) Thyme (*Thymus vulgaris* L.) Oregano (*Origanum vulgare* L.)	γ-rays/ 10	No significant effect on the antioxidative capacity.	Brandstetter, Berthold, Isnardy, Solar, and Elmadfa (2009)

Table 1 Effects of irradiation on antioxidants (continued)

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Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
Lotus rhizomes (*Nelumbo nucifera* Gaerth)	γ-rays/ 1-6	**Increase** of extraction yield and phenolic contents with increase of radiation dose. Enhancement of DPPH scavenging activity	Khattak, Simpson, and Ihasnullah (2009)
Cumin seeds *(Cuminum cyminum* L.)	γ-rays/ 1-10	No significant difference on all antioxidant parameters.	Kim, J.H, Shin, Hwang, Srinivasan, Kim, J.K., Park, Byun, and Lee, (2009)
Triphala (a mixture of *Emblica officinalis* Gaertn., *Terminalia chebula* Retz. and *Terminalia bellirica* (Gaertn.)Roxb.)	γ-rays/ 1-25	**Increasing** concentration of gallic acid, total phenolic contents and antioxidant properties with increasing radiation doses.	Kumari (2009)
Glycyrrhiza glabra L. roots	γ-rays/ 5-25	Phenolic contents were not significantly different at 5-15 kGy, but **increased** at 20-25 kGy. The DPPH scavenging activity significantly **increased** in all irradiated samples.	Khattak and Simpson (2010)
Rice grains of three genotypes (*Oryza sativa* L.) (white, red and black rice)	γ-rays/ 2-10	The doses of 2-10 kGy significantly decreased three phenolic acids (p-coumaric acid, ferulic acid and sinapinic acid). The doses of 6 and 8 kGy significantly **increased** total contents of anthocyanins and phenolic acids in black rice.	Zhu, Cai, Bao, and Corke (2010)
Satureja hortensis L. *Thymus vulgaris* L. *Thymbra spicata* L.	γ-rays/ 5.1	Decrease in total phenolic content and DPPH radical scavenging activity.	Gumus, Albayrak, Sagdic, and Arici (2011)
Pomegranate peels (*Punica granatum* L.)	γ-rays/ 5-25	Total phenolic content and antioxidant activity were positively correlated and showed a significant **increase** at 10 kGy.	Mali, Khedkar, and Lele (2011)
Clary sage seeds (*Salvia sclarea* L.)	γ-rays/ 2.5-7	All doses had negative effects on antioxidant activity.	Yalcin, Ozturk, Tulukcu, and Sagdic (2011)

Table 2 Effects of irradiation on volatile compounds

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
10 phytopreparations	E-beam/ 10	The content of essential oils did not change significantly.	Owczarczyk et al. (2000)
Thymus vulgaris L. *thymoliferum* *Eucalyptus radiate* A.Cunn. ex DC. *Lavandula angustifolia* Mill.	E-beam and γ-rays /25	No qualitative or quantitative significant changes in the contents and yields of essential oils.	Haddad and Quetin-Leclercq (2007)
Turmeric (*Curcuma longa* L.)	γ-rays/ 10	No detectable differences of the aromatic compounds.	Chatterjee, Variyar, Achyut, Padwal-Desai, and Bongirwar (2000)
Saffron (*Crocus sativus* L.)	γ-rays/ 2.5-5	No significant changes in the volatile essential oil constituents.	Zareena, Variyar, Gholap, and Bongirwar (2001)
Fresh cilantro leaves (*Coriandrum sativum* L.)	γ-rays/ 1-3	Minimal effect on volatile compounds compared with the losses that occurred during storage.	Fan and Sokorai (2002)
Nutmeg (*Myristica fragrans* Houtt.)	γ-rays/ 1-10	A dose-dependent breakdown of glycosidically bound volatile compounds was observed.	Ananthakumar, Variyar, and Sharma (2006)
Black cumin (*Nigella sativa* L.)	γ-rays/ 2.5-10	The percentages of unsaturated fatty acids decreased; trans fatty acid levels **increased.**	Arici, Colak, and Gecgel (2007)
Angelica gigas Nakai	γ-rays/ 1-20	Oxygenated terpenes such as β-eudesmol, α-eudesmol and verbenone were **increased** but did not correlate with the irradiation dose. The yields of active substances were **increased.**	Seo, Kim, J.H., Song, Kim, D.H., Byun, Kwon, and Kim, K.S. (2007)
Licorice roots (*Glycyrrhiza uralensis* Fisch.)	γ-rays/ 1-20	No major qualitative and quantitative loss of volatile compounds.	Gyawali, Seo, Shim, Ryu, Kim, W., You, and Kim, K.S. (2008)
Houttuynia cordata Thunb.	γ-rays/ 10	No significant difference on the volatile oils: hexahydrofarnesyl acetone, phytol, decanoic acid, dodecanoic acid, octadecanol, caryophyllene oxide, 2-undecanone and menthol.	Ryu, Shim, Jung, Jun, Jo, Song, Kim, K., and Kim, Y. (2008)

Table 2 Effects of irradiation on volatile compounds (continued)

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
Oregano (*Origanum vulgare* L.)	γ-rays/ 10	No changes in the chemical composition and the content of volatile oils.	Sádecká and Polovka (2008)
Cinnamon (*Cinnamomum verum* J.Presl)	γ-rays/ 10-25	Decrease in volatile compounds.	Salum, Araújo, Fanaro, Purgatto, and Villavicencio (2009)
Paeoniae Radix (*Paenia albiflora var. trichocarpa* Bunge)	γ-rays/ 1-10	No difference in the types of volatile compounds.	Shim, Hwang, Ryu, Jung, Seo, Kim, H., Song, Kim, J., Lee, Byun, Kwon, and Kim, K. (2009)
Black pepper (*Piper nigrum* L.)	γ-rays/ 5-30	Significant changes of volatile compounds after 30 kGy or heat treatment.	Sádecká (2010)

Table 3 Effects of irradiation on other active compounds and biological activities

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
10 phytopreparations	E-beam/ 10	Glycosides, triterpene saponins, oleanosides and plants mucus did not change significantly. Pharmacological activity such as diuretic action, spasmolytic action, cholagogic action, digestion, antibacterial action, calmative action and anti-inflammatory action has been found satisfactory.	Owczarczyk et al. (2000)
Sea buckthorn (*Hippophae rhamnoides* L.)	E-beam/ 3-20	A slight reduction in the alkaline phosphatase even at 3 kGy. At doses higher than 5 kGy, inhibitory effect on phospholipase A_2 began to change into a stimulating one.	Minea et al. (2007)
Senna leaves (*Senna alexandrina* Mill.)	γ-rays/ 10-25	No changes in sennoside content and composition.	Van Doorne, Bosch, Zwaving, and Elema (1988)
Curcuma domestica Valeton (*Curcuma longa* L.)	γ-rays / 10-50	No significant change on curcumin content.	Chosdu, Erizal, Iriawan, and Hilmy (1995)

Table 3 Effects of irradiation on other active compounds and biological activities (continued**)**

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
Thyme (*Thymus vulgaris* L) Cinnamon (*Cinnamomum verum* J. Presl) Coriander (*Coriandrum sativum* L.) Caraway (*Carum carvi* L.) Pimento (*Pimenta dioica* (L.) Merr.) Paprika (*Capsicum annuum var. angulosum* Mill.) Black pepper (*Piper nigrum* L.)	γ-rays/ 10	No distinct qualitative or quantitative chemical changes based on spectrophotometric analysis.	Josimović and Čudina (1987)
Dried leaves of marjoram (*Majorana hortensis* Moench) Rhizomes of ginger (*Zingiber officinale* Roscoe) Powdered hot pepper (*Capsicum annum* L.)	γ-rays / 5-30	Reduction in terpenes (converted to monoterpe-nesalcohols) of marjoram was observed. Ginger was more sensitive to irradiation. A slight, but significant effect on the capsaicin in hot pepper.	Farag, Aziz, and Attia (1995)
Nutmeg (*Myristica fragrans* Houtt.)	γ-rays/ 10	A 6-fold **increase** in myristicin content.	Variyar et al. (1998)
21 Korean medicinal herbs	γ-rays/ 10	No significant effect on anticomplement function.	Byun et al. (1999)
Saffron (*Crocus sativus* L.)	γ-rays/ 2.5-5	HPLC revealed a decrease in glucosides and an **increase** in aglycon content.	Zareena et al. (2001)
Nutmeg (*Myristica fragrans* Houtt.)	γ-rays/2.5-10	The lipid profiles were changed.	Niyas, Variyar, Gholap, and Sharma (2003)
Japanese honeysuckle (*Lonicera japonica* Thunb.)	γ-rays/ 10-30	No influence on xanthine oxidase and the nitrite scavenging ability. Tyrosinase inhibition **increased** by irradiation doses.	Byun, Jo, Jeon, and Hong (2004)
Soybean (*Glycine max* (L.) Merr.)	γ-rays/ 0.5-5	Decrease in content of glycosidic conjugates and an **increase** in aglycons.	Variyar et al. (2004)
Paeoniae Radix (*Paeonia albiflora var. trichocarpa* Bunge)	γ-rays/ 10	HPLC chromatogram of paeoniflorin was similar with that of the non-irradiated sample and the quantity of paeoniflorin did not change significantly with irradiation.	Yu, Jeong, Park, Oh, Jung, and Jo (2004)

Table 3 Effects of irradiation on other active compounds and biological activities (continued)

Medicinal plants	Types of radiation/ irradiation doses (kGy)	Major findings	References
Velvet bean seeds (*Mucuna pruriens* L.)	γ-rays/ 2.5-30	Tannin did not differ significantly up to 7.5 kGy, while it significantly **increased** at higher doses.	Bhat et al. (2007)
Sopoongsan (an oriental medicinal prescription including 12 medicinal herbs: *Nepeta japonica* Maxim. *Glycyrrhiza uralensis* Fisch. *Panax ginseng* C.A.Mey. *Poria cocos* F.A. Wolf *Bombyx mori* L. *Cnidium officinale* Makino *Peucedanum japonicum* Thunb. *Agastache rugosa* (Fisch. & C.A.Mey.) Kuntze *Dendrobium nobile* Lindl. *Angelica koreana* Maxim. *Citrus unshiu* Marcow. *Magnolia officinalis* Rehder & E.H.Wilson	γ-rays/ 5-20	No change on superoxide dismutase, xanthine oxidase, melanoma cell growth inhibition and anti-microbial activity.	Lee, Park, Son, Jo, Byun, and An (2007)
Velvet bean seeds (*Mucuna pruriens* L.)	γ-rays / 2.5-30	Unsaturated fatty acids decreased significantly. However, linoleic acid which was not present before iradiation detected after irradiation.	Bhat, Sridhar, and Seena (2008)
Curcuma longa L. *Andrographis paniculata* (Burm.f.) Nees	γ-rays/ 10	No significant difference on curcuminoids of *Curcuma longa* L. nor total lactone of *Andrographis paniculata* (Burm.f.) Nees	Thongphasuk P. et al. (2008)
Trigonella foenum-graecum L.	γ-rays/ 10	HPLC profile showed no change in the levels of phytochemicals up to 10 kGy.	Gupta, Bajpai, Mishra, Saxena, and Singh (2009)
Andrographis paniculata (Burm.f.) Nees	γ-rays/ 5-10	No influence on anti-inflammatory activity.	Mamatha, Kalpana, Patil, Purnima, Ashok, Kushal, Soujanya, and Gokul (2010)
Pumpkin seeds (*Cucurbita moschata* Duchesne)	γ-rays/ 10	No effect on antimicrobial activity.	Abd EI-Aziz and Abd EI-Kalek (2011)

3. Discussion

From those reviewed above, inconsistent results of the effects of irradiation on the antioxidant levels have been reported. According to the 33 studies listed in Table 1, 11 studies reported an increased antioxidant level, no effect of irradiations was observed on 12 studies whereas 7 studies indicated a decrease of antioxidant levels. In addition, Perez, Caldero, and Croci (2007) reported that the effects of irradiation were dependent upon the extraction conditions.

Harrison and Were (2007) suggested that the increased phenolic content in gamma-irradiated almond skin extract could be attributed to the release of phenolic compounds from glycosidic components and degradation of larger phenolic compounds into smaller ones. Variyar et al. (1998) and Khattak et al. (2008) reported that the increase in the phenolic contents was associated with the degradation of tannins as a result of irradiation. Plants with appreciable amounts of hydrolysable tannins may be more susceptible to irradiation compared with condensed tannins present in other spices (Khattak et al., 2008).

The studies on the effects of irradiation on the volatile compounds are also contradictory. From 14 studies, 9 studies showed insignificant effects on volatile compounds, but 3 studies reported a decrease of volatile compounds. Another study by Arici et al. (2007) showed a decrease of unsaturated fatty acids and an increase of trans fatty acids. In addition, Seo et al. (2007) indicated an increase of oxygenated terpenes.

From the 20 studies reported on the effects of irradiation on other compounds and biological activities, 5 studies showed a change in chemical patterns and 11 studies indicated no effects from irradiations. Variyar et al. (1998) demonstrated a 6-fold increase in myristicin and Byun et al. (2004) reported that there was no effect of irradiation on xanthine oxidase and the nitrite scavenging ability; however, tyrosinase inhibition was increased.

Effects of irradiation on active components, exclusive of antioxidant and volatile compounds, can be dependent on various factors including radiation dose, dose rate, components of raw materials, sample state (solid or dry), extraction solvent, extraction procedures, packaging, time delay between the irradiation process and the measurement, conditions (temperature and oxygen exposure during and after irradiation), and storage time (Crawford & Ruff, 1996; Khattak et al., 2008; Alothman, Bhat, & Karim, 2009; Polovka & Suhaj, 2010).

Crucq, Deridder, and Tilquin (2005) stated that the radioresistance of pharmaceuticals may depend on the conditions of irradiation and the best procedure is to irradiate the drugs in the solid state. In addition, Sadecka (2007) suggested to standardise analytical procedures to obtain results that are intercomparable.

According to the currently available data cited in table 1, 2 and 3, the effects of irradiation on active components of medicinal plants are rather difficult to conclude. More studies and details on specific materials (type and parts of plants, sample state: solid or liquid, fresh or dried, moisture content), irradiation processes (type of irradiation, irradiation doses, dose rate, temperature of the samples during irradiation) and experimental procedures (determination methods,extraction: procedure and solvents, exposure time, storage time, conditions during storage such as temperature, light, oxygen exposure, packaging use of desiccator) are required. In addition the determination of the medicinal plant expiration date should also be accounted for when considering the effects of irradiation.

4. Conclusion

Gamma irradiation is accepted as an effective preservative method. The information from the studies of the effects of irradiation on active components in medicinal plants is contradictory. Because the specific effects of irradiation are known for individual plants reviewed in this study, component activity can be accurately predicted. To conclude, more work and details on materials, irradiation processes, and experiments are required for further intercomparisons. Since irradiation may affect glycosidic compounds, the future research should focus on the active glycoside compounds such as cardiac glycosides, saponins and glucosinolates etc. Finding the optimum conditions for irradiation of each medicinal plant will reduce detrimental effects of irradiation on the plants.

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