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EFFECT OF GAMMA IRRADIATION ON BIOACTIVE COMPOUNDS OF MEDICINAL PLANTS

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Abstract

Gamma irradiation has various applications in the agricultural, medical and industrial fields. It is widely used as a method of microbial decontamination and for mutation breeding in plants. Particular emphasis is placed on the ability of gamma rays to stimulate cellular metabolism to synthesize medicinally valuable secondary metabolites. The aim of this paper is to review the published results on the effect of gamma irradiation on bioactive compounds of medicinal plants. Comparison of different studies showed that the effects observed after radiation exposure depended on several factors, such as species, radiation dose, sample type, sample state (solid or liquid, fresh or dry), extraction solvent and extraction method. Current findings are good indicators of the potential application of gamma irradiation to produce high quality raw materials to meet the requirements of the food and pharmaceutical industries.

***Key words**: radiation dose, phenolic compounds, volatile compounds, biological activity.*

INTRODUCTION

In human society, gamma irradiation has various applications in agriculture, medicine and other biotechnological processes. In agriculture, it is used for microbial decontamination, to reduce post-harvest losses by suppressing sprouting and to extend the shelf life of food (Emovon, 1996). Gamma irradiation is also used to improve the physiological and biochemical processes in plants, an example being the stimulation of the synthesis of medicinally valuable secondary metabolites (Aly, 2010).
Gamma rays are ionizing radiation that contains high energy photons with a higher penetration capacity than alpha and beta rays, causing the ionization of matter and plants through indirect interaction (Kovács & Keresztes, 2002; Vandenhove et al., 2010). Gamma radiation interacts with atoms or molecules in the cell, especially with water, producing free radicals that can change important components of plant cells, affecting differently the morphology, physiology, anatomy and biochemistry of plants depending on the radiation dose (Kovács & Keresztes, 2002; Ashraf et al., 2003). High doses of gamma radiation disrupts hormonal balance, protein synthesis, enzymatic activity, gas exchange in leaves and water exchange in plants (Esfandiari et al., 2008; Kiong et al., 2008). These effects induce changes in cell structure and plant metabolism; for example alteration of photosynthesis, dilatation of thylakoid membranes, accumulation of phenolic compounds and modulation of the antioxidant system (Kim et al., 2004; Wi et al., 2006; Ashraf, 2009).
According to the World Health Organization, irradiation doses up to 10 kGy are considered non-toxic to food products (WHO, 1999). However, irradiation can produce qualitative and quantitative changes in plant phytochemicals.
The aim of this paper is to review the published results on the effect of gamma irradiation on bioactive compounds of medicinal plants.

MATERIALS AND METHODS

A systematic and comprehensive research of the literature was conducted using a set of representative keywords, such as "gamma irradiation", "medicinal plants", "bioactive compounds" and "biological activity". From the accessed scientific databases, 67 studies were used in this review study.

RESULTS AND DISCUSSIONS

The results of studies on the effect of gamma irradiation on bioactive compounds of medicinal plants are contradictory.

Regarding the effects produced by gamma radiation on the phenolic content, different results were reported. Irradiation at 10, 20 and 30 kGy did not produce significant changes on phenolic compounds and flavonoids in some Brazilian medicinal herbs (Koseki et al., 2002). There were also no changes in the phenolic content of thyme and peppermint irradiated at 2, 5 and 10 kGy (Pereira et al., 2016). Instead, irradiation at 10 kGy increased the concentration of phenolic compounds in ginkgo extract (Pereira et al., 2015). Pereira et al. (2018) also reported an increase in lithospermic acid A in lemon balm and 5-O-caffeoylquinic acid in bastard balm irradiated at 1 and 10 kGy. Irradiation at 15 kGy increased the phenolic content in *Brassica nigra* L. (0.1%), *Cassia senna* L. (1.3%), *Cymbopogon schoenanthus* L. (24.9%), *Lepidium sativum* L. (25.6%), *Cassia senna* L. (70%) and decreased the phenolic content in *Trigonella foenumgraecum* L. (4.1%), *Hibiscus sabdariffa* L. (5.1%), *Acacia nilotica* L. (14%) and *Cymbopogon citrates* L. (33%) (Polovka & Suhaj, 2010).

There are reported studies in which gamma irradiation had a different effect on different phenolic compounds. Variyar et al. (1998) found that irradiation at 10 kGy led to an increase in the content of gallic acid and syringic acid in clove, while the content in synapic acid, ferulic acid and p-coumaric acid decreased by about half and that of caffeic acid and gentisic acid remained unchanged. In the case of nutmeg, with the exception of p-coumaric acid and protocatechuic acid, which remained unchanged, irradiation produced changes in the content of other phenolic acids compared to the control samples.

Campos et al. (2005) reported a 5.2% decrease in tannic acid in *Maytenus aquifolium* Martius irradiated at 100 Gy.

The effect of gamma irradiation on phenolic compounds also depended on the radiation dose applied. Kiong et al. (2008) reported that rosamarinic acid content was lowest (5.27 mg/g fw) in *Orthosiphon stamineus* plantlets irradiated at 10 Gy and highest (8.40 mg/g fw) in plants irradiated at 30 Gy.

The different effects of gamma irradiation on phenolic compounds can be attributed to their different extraction capacity. Also, the increased phenolic content may be associated with the degradation of tannins due to irradiation, plants with large amounts of hydrolysable tannins being more sensitive to irradiation compared to those containing condensed tannins (Variyar et al., 1998; Khattak et al., 2008).

Regarding the effect of gamma radiation on antioxidant activity, there are studies that have shown a stimulatory effect of irradiation (Variyar et al., 2004; Štajner et al., 2007; Suhaj & Horvathova, 2007, Khattak et al., 2009; Mohamed, 2009; Khattak & Simpson, 2010; Mali et al., 2011; Taheri et al., 2014; Ashouri Sheikhi et al., 2016) or no effect of irradiation observed in other studies (Byun et al., 1999; Chatterjee et al., 1999; Horvathova et al., 2007; Thongphasuk et al., 2008; Brandstetter et al., 2009; Kim et al., 2009; Akshatha et al., 2013), while other studies have indicated a decrease in antioxidant levels (Lampart-Szczapa et al., 2003; Gumus et al., 2011; Yalcin et al., 2011).

Research results on the effect of gamma irradiation on volatile compounds are also contradictory. There are studies that have shown an increase in the content of volatile compounds after gamma irradiation (Gyawali et al., 2006), insignificant effects of irradiation (Chatterjee et al., 2000; Zareena et al., 2001; Koseki et al., 2002; Haddad & Quetin-Leclercq, 2007; Gyawali et al., 2008; Ryu et al., 2008; Sádecká & Polovka, 2008; Shim et al., 2009), while one study has shown a decrease in the content of volatile compounds (Salum et al., 2009).

Some research has shown that irradiation had different effects on different essential oil compounds. Variyar et al. (1998) reported that the content of myristicin, 1-terpinene-4-ol and á-terpeniol increased, while that of elemicin, α-pinene and sabinene decreased in the irradiated nutmeg compared to the control sample. Among the constituents of Korean angelica essential oil, oxygenated terpenes, such as verbenone, α-eudesmol and β-eudesmol increased after gamma irradiation (Seo et al., 2007). Irradiation led to an increase of trans fatty acids and a decrease of unsaturated fatty acids in *Nigella sativa* L. (Arici et al., 2007). Gamma irradiation also significantly decreased the content of unsaturated fatty acids in *Mucuna pruriens* L. Although linoleic acid was not detected in the non-irradiated sample, it was detected in the irradiated samples (Bhat et al., 2008).

The effect of gamma irradiation on volatile compounds also depended on the radiation dose applied. Ilyas & Naz (2014) reported that maximum amount of essential oil and curcuminoids in the rhizomes of turmeric was recorded at 50-60 Gy, while higher doses of gamma irradiation (100 Gy) reduced the amount of oil and curcuminoids.

Studies on the effect of gamma radiation on other chemical compounds have also been reported.

For example, irradiation at 10 kGy led to a significant decrease in the total ascorbate content in oregano, sage, nutmeg, cinnamon and black pepper, and a significant decrease of carotenoids in sage, rosemary, oregano, cinnamon, parsley and bird pepper (Calucci et al., 2003).

Chung et al. (2006) reported a 400% increase in the total shikonin content in *Lithospermum erythrorhizon* irradiated at 16 Gy, by 240% in plants irradiated at 2 Gy and by 180% in plants irradiated at 32 Gy.

Gamma irradiation at 110 Gy doubled the value of the alkaloid in *Atropa belladonna* L. (Abdel-Hady et al., 2008).

The gamma radiation dose of 15 Gy slightly increased the stevioside content, while other doses (5, 10 and 20 Gy) showed a negative effect on the stevioside content in the callus of *Stevia rebaudiana* Bert. (Khalil et al., 2015).

No changes were reported in the sennoside content in senna irradiated at 10-25 kGy, in the curcumin content in turmeric irradiated at 10-50 kGy and in the paeoniflorin content in *Paeonia* Radix irradiated at 10 kGy (Van Doorne et al., 1988; Chosdu et al., 1995; Yu et al., 2004). Also, after irradiation up to 17.8 kGy, the content of flavonol glycosides and caffeine in *Ginkgo biloba* L. and *Paullinia cupana* H.B.K., respectively, was not modified (Soriani et al., 2005).

Byun et al. (2004) reported that irradiation had no effect on xanthine oxidase and the nitrite scavenging capacity in *Lonicera japonica* Thunb.; however, tyrosinase inhibition was increased.

Studies on black pepper, cinnamon, paprika, caraway, pimento, thyme, coriander and fenugreek irradiated at 10 kGy showed no qualitative or quantitative chemical changes compared to the control sample (Josimović & Čudina, 1987; Gupta et al., 2009). Instead, phytic acid was not detected in velvet bean seeds irradiated at 15 kGy (Bhat et al., 2007).

Regarding the effect of gamma irradiation on biological activities, the studies did not show any influence of irradiation on the anti-inflammatory and antimicrobial activity (Mamatha et al., 2010; Abd EI-Aziz & Abd EI-Kalek, 2011).

The main reported results on the effect of gamma irradiation on bioactive compounds of medicinal plants are presented in Table 1.

Table 1. Effect of gamma irradiation on bioactive compounds of medicinal plants

Medicinal plants	Radiation dose	Results	Authors
Capsicum annuum var. *angulosum* Mill. (paprika) *Carum carvi* L. (caraway) *Cinnamomum verum* J. Presl (cinnamon) *Coriandrum sativum* L. (coriander) *Pimenta dioica* L. Merr. (pimento) *Piper nigrum* L. (black pepper) *Thymus vulgaris* L. (thyme)	10 kGy	No significant qualitative or quantitative chemical changes.	Josimović & Čudina (1987)
Senna alexandrina Mill. (senna)	10-25 kGy	No changes in the content of sennoside.	Van Doorne et al. (1988)
Curcuma longa L. (turmeric)	10-50 kGy	No significant changes in curcumin content.	Chosdu et al. (1995)
Syzygium aromaticum L. (clove)	10 kGy	Increases in gallic acid and syringic acid content; decreases in the content of synapic acid, ferulic acid and p-coumaric acid; no effect on the content of caffeic acid and gentisic acid.	Variyar et al. (1998)
Myristica fragrans Houtt. (nutmeg)	10 kGy	Increases in the content of myristicin, 1-terpinene-4-ol and á-terpeniol; decreases in the	Variyar et al. (1998)

Medicinal plants	Radiation dose	Results	Authors
		content of sabinene, α-pinene and elimicin; no effect on the content of p-coumaric acid and protocatechuic acid.	
21 Korean medicinal herbs	10 kGy	No significant effect on antioxidants, nitrite scavenging and electron donation capacity.	Byun et al. (1999)
Curcuma longa L. (turmeric)	10 kGy	No effect on antioxidant activity.	Chatterjee et al. (1999)
Curcuma longa L. (turmeric)	10 kGy	No significant changes in aromatic compounds.	Chatterjee et al. (2000)
Crocus sativus L. (saffron)	2.5-5 kGy	No significant changes in the constituents of essential oil.	Zareena et al. (2001)
Cynara scolymus L. (artichoke) *Nasturtium officinale* R. Br. (watercress) *Ocimum basilicum* L. (sweet basil) *Rosmarinus officinalis* L. (rosemary)	10, 20 and 30 kGy	No significant changes in essential oils, phenolic compounds, flavonoids and tannins.	Koseki et al. (2002)
Capsicum frutescens L. (bird pepper) *Cinnamomum verum* J. Presl (cinnamon) *Myristica fragrans* Houtt. (nutmeg) *Ocimum basilicum* L. (basil) *Origanum vulgare* L. (oregano) *Petroselinum sativum* Hoffm. (parsley) *Piper nigrum* L. (black pepper) *Rosmarinus officinalis* L. (rosemary) *Salvia officinalis* L. (sage)	10 kGy	Significant decrease in total ascorbate in oregano, sage, nutmeg, cinnamon and black pepper; significant decrease in carotenoids in sage, rosemary, oregano, cinnamon, parsley and bird pepper.	Calucci et al. (2003)
Lupinus angustifolius L. (lupin) *Lupinus albus* L. (white lupin) *Lupinus luteus* L. (yellow lupin)	1-10 kGy	Increasing irradiation doses reduced the antioxidant effects.	Lampart-Szczapa et al. (2003)
Lonicera japonica Thunb. (japanese honeysuckle)	10-30 kGy	No influence on xanthine oxidase and the nitrite scavenging capacity. Tyrosinase inhibition increased with radiation dose.	Byun et al. (2004)
Paeonia albiflora var. *trichocarpa* Bunge (*Paeoniae* Radix)	10 kGy	No significant changes in the amount of paeoniflorin.	Yu et al. (2004)
Glycine max L. Merr. (soybean)	0.5-5 kGy	Increases in DPPH free radical-scavenging activity; decreases the content in glycosidic conjugates; increases the content in aglycons.	Variyar et al. (2004)
Ginkgo biloba L. (ginkgo) *Paullinia cupana* H.B.K. (guarana)	5.5-17.8 kGy	No significant difference in the flavonol glycosides content of ginkgo and the caffeine content of guarana.	Soriani et al. (2005)
Maytenus aquifolium Martius ("espinheira-santa")	10, 20, 40, 60, 80 and 100 kGy	Decreases the tannic acid content by 5.2 % at 100 Gy.	Campos et al. (2005)
Lithospermum erythrorhizon (purple gromwell)	2, 16 and 32 Gy	Increases in total shikonin content.	Chung et al. (2006)
Allium fistulosum L. (welsh onion)	1, 3, 5, 10 and 20 kGy	Increasing the total content of volatile compounds by 31.60% at 10 kGy and by 24.85% at 20 kGy.	Gyawali et al. (2006)
Angelica gigas Nakai (Korean angelica)	1, 3, 5, 10 and 20 kGy	Increases in oxygenated terpenes.	Seo et al. (2007)
Mucuna pruriens L. (velvet bean)	2.5-30 kGy	Increases in total phenolic content; no significant difference in tannin content up to 7.5 kGy; significant increase in tannin content at higher doses.	Bhat et al. (2007)
Nigella sativa L. (black cumin)	2.5-10 kGy	Decreases unsaturated fatty acids content; increases the content of trans fatty acids.	Arici et al. (2007)
Eucalyptus radiate A. Cunn. ex DC. (narrow-leaved peppermint) *Lavandula angustifolia* Mill. (lavender) *Thymus vulgaris* L. *thymoliferum* (thyme)	25 kGy	No significant qualitative or quantitative changes in the compounds of essential oils.	Haddad & Quetin-Leclercq (2007)
Origanum vulgare L. (oregano)	30 kGy	Insignificant effect on DPPH radical-scavenging capacity.	Horvathova et al. (2007)
Rosmarinus officinalis L. (rosemary)	30 kGy	Increases in total phenolic content in water extracts; no effect on the total phenolic content of methanol and ethanol extracts.	Pérez et al. (2007)
Glycine max L. Merr. (genotype Ana)(soybean)	1-10 kGy	Increases in total phenolic content and antioxidant activity.	Štajner et al. (2007)
Syzygium aromaticum L. Merr. & L.M. Perry (clove) *Zingiber officinale* Roscoe (ginger)	5-30 kGy	The increase in the oxidative substances content with the radiation dose.	Suhaj & Horvathova (2007)
Nigella sativa L. Kalungi (black cumin)	2, 4, 8, 10, 12 and 16 kGy	Increases in total phenolic content and enhances free radical-scavenging activity.	Khattak et al. (2008)
Glycyrrhiza uralensis Fisch. (licorice)	1, 3, 5, 10 and 20 kGy	No major qualitative and quantitative diferences in volatile compounds.	Gyawali et al. (2008)
Atropa belladonna L. (belladonna)	50, 80, 110 and 150 Gy	Doubling the alkaloid value at 110 Gy.	Abdel-Hady et al. (2008)
Orthosiphon stamineus (java)	0, 10, 20, 30,40, 50, 60 and 70 Gy	Rosamarinic acid content was lowest in plants irradiated at 10 Gy and highest in plants irradiated at 30 Gy.	Kiong et al. (2008)
Andrographis paniculata (Burm.f.) Nees (King	10 kGy	No significant difference in the DPPH radical-	Thongphasuk et al.

Medicinal plants	Radiation dose	Results	Authors
of Bitters) *Curcuma longa* L. (turmeric)		scavenging ability. No significant changes in the curcuminoids content of turmeric and in the total lactone content of King of Bitters	(2008)
Houttuynia cordata Thunb. (chameleon)	10 kGy	No significant differences in the following volatile oil compounds: decanoic acid, dodecanoic acid, 2-undecanone, octadecanol, caryophyllene oxide, phytol, menthol and hexahydrofarnesyl acetone.	Ryu et al. (2008)
Origanum vulgare L. (oregano)	10 kGy	No changes in the content of volatile compounds.	Sádecká & Polovka (2008)
Mucuna pruriens L. (velvet bean)	2.5-30 kGy	Significant decreases in unsaturated fatty acids content. Although linoleic acid was not detected in the non-irradiated sample, it was detected in the irradiated samples.	Bhat et al. (2008)
Eryngium foetidum L. (culantro)	10, 20 and 40 Gy	Increases in the total phenolic content, flavonoids, tannin and saponin; enhances reactive scavenging capacity.	Mohamed (2009)
Trigonella foenum-graecum L. (fenugreek)	10 kGy	No changes in the content of phytochemicals.	Gupta et al. (2009)
Origanum vulgare L. (oregano) *Salvia officinalis* L. (sage) *Thymus vulgaris* L. (thyme)	10 kGy	No significant effect on antioxidant capacity.	Brandstetter et al. (2009)
Nelumbo nucifera Gaerth (lotus)	1-6 kGy	Increases in phenolic content with increasing radiation dose; enchances DPPH scavenging activity.	Khattak et al. (2009)
Cuminum cyminum L. (cumin)	1-10 kGy	No significant differences in the content of antioxidant compounds.	Kim et al. (2009)
Paenia albiflora var. *trichocarpa* Bunge (*Paeoniae* Radix)	1-10 kGy	No differences in the content of volatile compounds.	Shim et al. (2009)
Cinnamomum verum J.Presl (cinnamon)	10-25 kGy	Decreases in the content of volatile compounds.	Salum et al. (2009)
Andrographis paniculata (Burm.f.) Nees (King of Bitters)	5-10 kGy	No influence on anti-inflammatory activity.	Mamatha et al. (2010)
Glycyrrhiza glabra L. (licorice)	5-25 kGy	No significant differences in phenolic content at 5-15 kGy; increases in phenolic content at 20-25 kGy; significant increases DPPH scavenging activity in all irradiated samples.	Khattak & Simpson (2010)
Brassica nigra L. Koch (black mustard) *Cassia senna* L. (senna) *Cymbopogon schoenanthus* L. (lemon grass) *Lepidium sativum* L. (garden cress)	5-30 KGy	Slight increase in phenolic content at 15 kGy.	Polovka & Suhaj (2010)
Acacia nilotica L. (gum arabic tree) *Cymbopogon citrates* L. (lemon grass) *Hibiscus sabdariffa* L. (roselle) *Trigonella foenum-graecum* L. (fenugreek)	5-30 KGy	Decreases in phenolic content at 15 kGy.	Polovka & Suhaj (2010)
Satureja hortensis L. (summer savory) *Thymbra spicata* L. (Mediterranean thyme) *Thymus vulgaris* L. (thyme)	5.1 kGy	Decreases in total phenolic content and DPPH radical scavenging activity.	Gumus et al. (2011)
Punica granatum L. (pomegranate)	5-25 kGy	Significant increases in total phenolic content and antioxidant activity at 10 kGy.	Mali et al. (2011)
Salvia sclarea L. (clary sage)	2.5-7 kGy	Negative effect on antioxidant activity.	Yalcin et al. (2011)
Cucurbita moschata Duchesne (pumpkin)	10 kGy	No effect on antimicrobial activity.	Abd EI-Aziz & Abd EI-Kalek (2011)
Terminalia arjuna Roxb. (arjuna)	25, 50, 100, 150 and 200 Gy	No significant increases in DPPH scavenging activity levels; increases in proline and phenolic content.	Akshatha et al. (2013)
Curcuma longa L. (turmeric)	10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 Gy	Maximum yield of essential oil and curcuminoids at 50-60 Gy; decreases the amount of oil and curcuminoids at higher doses (100 Gy).	Ilyas & Naz (2014)
Curcuma alismatifolia var. *Sweet pink* (Siam tulip)	10, 15 and 20 Gy	Increases the content of phenolic compounds, flavonoids, fatty acids and antioxidant activity as the radiation dose increases.	Taheri et al. (2014)
Stevia rebaudiana Bert. (stevia)	5, 10, 15 and 20 Gy	Slight increase in stevioside content at 15 Gy; negative effect of the other doses on stevioside content; increases in total phenolic content and total flavonoid content at 15 Gy; enhances antioxidant activity at 20 Gy.	Khalil et al. (2015)
Ginkgo biloba L. (ginkgo, maidenhair tree)	1 and 10 kGy	Increases the concentration of phenolic compounds at 10 kGy.	Pereira et al. (2015)
Ferula gummosa Bioss. (galbanum)	10, 15, 20 and 25 Gy	Increases in phenolic content and radical scavenging activity.	Ashouri Sheikhi et al. (2016)
Mentha x piperita L. (peppermint) *Thymus vulgaris* L. (thyme)	2, 5 and 10 kGy	No change in phenolic content and bioactive properties.	Pereira et al. (2016)
Melissa officinalis L. (lemon balm) *Melittis melissophyllum* L. (bastard balm)	1 and 10 kGy	Increases in lithospermic acid A in lemon balm and 5-O-caffeoylquinic acid in bastard balm.	Pereira et al. (2018)

Given the contradictory results of the studies reviewed, the effects of gamma irradiation on bioactive compounds of medicinal plants are quite difficult to conclude. These effects depend on several factors, such as species, radiation dose, sample type, sample state (solid or liquid, fresh or dry), extraction solvent and extraction method (Pérez et al., 2007; Khattak et al., 2008; Alothman et al., 2009; Polovka & Suhaj, 2010). For this reason, it is not possible to identify common trends to all compounds and/or plant species.

CONCLUSIONS

The effect of gamma irradiation on the bioactive compounds of medicinal plants depends on several factors, but the main ones are the species and the dose of radiation applied.

Current findings are good indicators of the potential application of gamma irradiation to produce high quality raw materials to meet the requirements of the food and pharmaceutical industries.

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