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THE EFFECT OF GAMMA IRRADIATION AND PHOSPHATIC FERTILIZATION ON GROWTH, YIELD AND CHEMICAL COMPOSITION OF CARAWAY PLANTS

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ABSTRACT: ***Recently, radiation technology is widely used to induce changes in plant characteristics for developing new products. So, a field experiment was carried out on alluvial clay soil at the Experimental Farm, Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt (30.52^{o}N and 30.99^{o}E) during the two successive growing winter seasons, i.e. 2012/2013 and 2013/2014 on caraway plants (Carum carvi L.) to evaluate both individual and combined effects of different doses of gamma rays (0, 20, 40 and 80 Gy) and different levels of phosphorus (P) fertilizer (0, 50, 75, 100 and 125% of the recommended dose which are 0, 100, 150, 200 and 250 kg ordinary super phosphate/fed, respectively, P_2O_5=15.5 %) on growth and yield components. The layout of this experiment was a split-plot design with the main plots that arranged in a randomized complete blocks design with three replicates.***

The results revealed that irradiation by gamma rays individual and/or combined with (P) fertilizer caused significant increases in vegetative growth characters, i.e. plant height (cm), number of main branches/plant and fresh weight of whole plant (g) along with yield and oil yield parameters, i.e. number of umbels/plant, dry weight of umbels/plant (g), fruit yield (g/plant and kg/fed), volatile oil % and oil yield (cc/plant and l/fed) as well as chemical composition, i.e. photosynthetic pigments, N, P, K, crude protein and total carbohydrate contents (%) in plants. The maximum increase in the most cases of (vegetative growth characters, yield parameters and oil production) was noticed by using gamma rays at (40 Gy) combined with (P) fertilizer at (200 kg/fed).There was a gradual increase in total carbohydrate content (%) as a result of using different levels of (P) fertilizer and reached its maxima by using the interaction of gamma rays at (40 Gy) combined with (P) fertilizer at (250 kg/fed). Finally, the interaction treatments of gamma rays at the low dose (20 Gy) + each of (P) fertilization at rates of (150 or 200 kg/fed) produced the maximum content of chlorophyll a in the first and second seasons, respectively. Moreover, it could be mentioned that the highest value of chlorophyll b was happened by exposing seeds to the moderate dose of gamma rays (40 Gy) and combined by each of (P) fertilization at (150 or 200 kg/fed) through the first and second seasons, respectively.

Key words: ***Caraway, Gamma rays, Phosphorus fertilizer, Vegetative growth parameters and Chemical compositions.***

INTRODUCTION

Caraway (*Carum carvi* L.) belongs to the family of Umbelliferae (Apiaceae) as an annual herb cultivated in Europe and in South Africa with stem up to about 1.5 m height (Saghir *et al*., 2012). The characteristic aroma and healing properties of *Carum carvi* come from essential oil. Fruits contain about 1-6% essential oil which consists of approximately 30 compounds (Sedlakova *et al.,* 2003). The main compounds in the oil content are carvone and limonene, which constitute about 95% of total compounds, while the others are usually

present only in traces. Also, caraway seeds contain lipids13-21%, fiber 13-19%, nitrogen compounds 25-35%, and water 9-13% (Kocourkova *et al*., 1999). Moreover, caraway seeds are used in meat, food and distillery industries due to its pleasant flavor and intense taste. Its fungicidal and antibacterial properties are important in pharmaceutical applications and also in manufacturing human and veterinary medicine (Sedlakova *et al*., 1998). Caraway is added to the feedstuff to increase milk production, improve taste and digestibility and reduce flatulence of cattle. It has also antiseptic, antispasmodic, pain sedative, depletive and antioxidant properties (Sembratowicz and Czech, 2005 and Dyduch *et al*., 2006) .

Radiation treatments have been the most frequently method that used to develop direct mutant varieties, accounting for about 85% of obtained varieties with gamma rays and 15% with x rays (Jain and Gupta, 2005). Gamma rays are electromagnetic radiation (ionizing radiation) with the highest energy level. Gamma rays affect the DNA molecule by rupturing of hydrogen bonds among the base pairs that breaks in one or both of the DNA strands. Therefore, they produce multiple effects in growth, physiological, morphological, cytological and gene expression levels in treated plants. These effects may be lethal or significantly positive which is a matter of chance. The plants showing desired effects can be chosen for further breeding (Dhanavel and Girija, 2009). Gamma rays belong to the ionizing radiation and interact with atoms or molecules that can damage or produce free radicals in cells. These radicals can damage or modify important component of plants e.g. alteration in photosynthesis, dilation of thylakoid membranes, modulation of the antioxidative system and also accumulation of phenolic compounds (Kim *et al*., 2000). Due to all of the above and also the economic value of gamma rays which lead to their wider application for the improvement of various plant species that compared to other ionizing radiations, gamma irradiation has a profound influence on plant growth and development by inducing genetically, physiological, biochemical, cytological, and morphogenetic changes in cells and tissues depending on the levels of irradiation (Akshatha *et al*., 2013).

Phosphorus is one of the 16 essential elements required for plant growth and considered one of the three most important nutrients plus nitrogen and potassium. Phosphorus is essential to many vital functions in the plant growth i.e. early rooting and seedling growth, improved winter hardiness, uniform maturity, seed formation and quality and increased water use efficiency. While these effects are more obvious, phosphorus plays also unseen roles such as in photosynthesis, energy storage and transfer, cell division and respiration. Leakage of phosphorus in crops leads to slower development, exhibit limited growth potential and also yield less than expected (Johnston, 2001). Egyptian farmers add the total amount of phosphorus fertilizer at the soil ploughing stage. Accordingly, most of the phosphorus content is fixed in an insoluble phase which is unavailable for plant uptake and leads to decrease phosphorus fertilizer use efficiency. Phosphorus reduction in plants has been shown to decrease the whole leaf area and it is clear that leaf area development is an important issue for plant production (Israel and Rufty, 1988; Fredeen *et al*., 1989 and Qiu and Israel, 1994). In addition, It has a vital role in the photosynthesis process which uses light energy in the presence of chlorophyll to merge carbon dioxide and water into simple sugars, with the energy being

captured in adenosine triphosphate (ATP). ATP is the energy source for different reactions that happen within the plant and also sugars are used as building blocks to produce other cell structural and storage components. Also, the nitrate metabolism is relative to the phosphorus addition as the absorption and reduction of nitrate is an energy-consuming process, and this energy is supplied by ATP which contains phosphorus (Wang and Li, 2004).

MATERIALS AND METHODS

The present investigation was carried out on alluvial clay soil at the Experimental Farm, Faculty of Agriculture, Menoufia University, Shebin El-Kom, Egypt (30.52ºN and 30.99ºE) during two successive growing winter seasons, i.e. 2012/2013 and 2013/2014 on caraway plants (*Carum carvi L.*) to evaluate both individual and combined effects of different doses of gamma rays (0, 20, 40 and 80 Gy) and different levels of (P) fertilizer (0, 50, 75, 100 and 125% of the recommended dose which are 0, 100, 150, 200 and 250 kg ordinary super phosphate/fed, respectively, P_2O_5=15.5%) on growth and yield components. All the agricultural practices beginning from the preparation of soil to planting until harvesting were carried out as recommended by Egyptian Ministry of Agriculture.

Before planting, representative surface soil samples (0 - 30 cm) were taken from the experimental soil. The soil samples were air - dried, ground, mixed well, sieved through a 2 mm sieve. The samples then were analyzed for determination of some physical and chemical properties. Also, the content of some available macro- and micronutrients according to the methods were described by Cottenie *et al*. (1982), Page *et al.* (1982) and Kim (1996). The obtained data were recorded in Table (1).

The Experimental Design

The experimental plots were 60 units including 4 doses of gamma rays × 5 levels of (P) fertilizer × 3 replicates. The area of each plot was 1.5 m ×1.5 m with three rows at (50 cm) apart and the distance between plants (30 cm). Each row contained 5 plants and consequently each plot contained 15 plants.

The experiment was carried out in a split plot design with the main plots arranged in a randomized complete blocks design, with three replicates. The main plots were planted with seeds which exposed to the irradiation treatments (0, 20, 40 and 80 Gy), while the sub- plots were treated with different level of (P) fertilizer (0, 50, 75, 100 and 125% of the recommended dose which are 0, 100, 150, 200 and 250 kg ordinary super phosphate/fed, respectively, P_2O_5=15.5 %). Before planting, at the final soil preparation, all treatments of ordinary super phosphate were added in one dose + (20 m^3/fed) of maturity compost. In two growing seasons, seeds of this study were kindly provided by Medicinal and Aromatic Plants Res. Dept., Hort. Res. Inst., Agric. Res. Center, Giza, Egypt. Then, seeds were exposed to three doses of gamma radiation at the atomic energy center in Nasr City, Cairo, Egypt- using cobalt 60 as a source. Seeds were sown on the first of October during the first and second seasons. After thinning directly (19 day from planting) and also after 75 days from sowing, all plots were received ammonium sulphate (21.5 % N) at rate of (200 kg/fed) in two equal doses. Also, all plots were fertilized with potassium sulphate (48 % K_2O) at the rate of (50 kg/fed) in one dose after one month from planting during two seasons. Through the growing period, all plots were irrigated around 2 weeks according to climate conditions.

Table (1): Some physio-chemical properties of the used soil and its content of available some macro and micro- nutrients.

Soil properties and units	Value
Particle size distribution (%)	
Coarse sand	6.35
Fine sand	14.50
Silt	25.00
Clay	54.15
Texture class	Clayey
Water holding capacity (%)	62.8
Organic matter (%)	1.90
PH (1:2.5 soil : water suspension)	7.55
EC_e in soil paste extract (dSm^{-1})	1.51
CEC (cmol/kg)	37.30
$CaCO_3$ (%)	4.60
Soluble cations (meq/l)	
Ca^{++}	4.48
Mg^{++}	1.81
Na^{+}	6.55
K^{+}	2.27
Soluble anions (meq/l)	
CO_3^{--}	--
HCO_3^{-}	1.44
Cl^{-}	10.30
SO_4^{--}	3.37
Available macronutrients (mg/kg soil)	
N	43.88
P	7.80
K	363.50
Available micronutrients (mg/kg soil)	
Fe	6.82
Mn	3.21
Zn	1.08

Preparation and analyses of plant samples

In both seasons at the end of the experiment, when fruits became greenish yellow in color (about six months from planting), the plants of each plot were harvested and translocated to a shade place to examine parameters as follows:-

1- Vegetative growth characteristics

Plant height (cm), number of main branches/plant, fresh weight of whole plant (g/plant), number of umbels/plant, dry weigh of umbels (g/plant), fruit yield (g/plant) and fruit yield (kg/fed).

2- Chemical constituents

Photosynthetic pigments (chlorophyll a, b and carotenoids) were determined in fresh leaves as the methods that described by Witham *et al*. (1971). Also, essential oil percentages were determined in the air dried fruits in both seasons as described by British Pharmacopea (1963).

The samples of the harvested plants were washed several times with a tap-water and then two times with distilled water, air-dried, oven-dried at 70 ^{o}C for 48 hour, ground separately to a fine powder in a stainless grinder and stored in plastic bags until analysis. The total carbohydrate (%) in the dried herb of caraway plants was determined by using the colorimetric method which described by Dubois *et al.* (1956). Whereas, a half g portion of each dried plant sample was digested by 5 ml of concentrated mixture of H_2SO_4 + $HClO_4$ at (5:0.5 ratio) according to Chapman and Pratt (1982). The content (%) of N, P and K were determined as described by Cottenie *et al.* (1982). Also, crude protein (%) was calculated by multiplying the values of N content (%) by 5.75 according to A.O.A.C. (1985).

Statistical analysis

The obtained data of growth parameters were exposed to proper statistical analysis of variance (ANOVA) by using Minitab computer program and the least significant difference (L.S.D.) were calculated at the level of 5 % (Barbara and Brain, 1994).

RESULTS AND DISCUSSION

Effect of different doses of gamma rays, phosphate fertilizer and their interactions on:

1-Vegetative growth characteristics

It should be pointed out that seed germination that started simultaneously ten days after sowing and the germination rate was 100% in the control as well as in the exposed seeds of caraway plants to different doses of gamma rays during the first and the second generations (data not shown). In general, gamma irradiation had significant impact on vegetative growth characteristics, i.e. plant height, number of main branches and fresh weight of whole plant as shown in Table (2). The highest enhancement in these studied characteristics were observed with the application of the moderate dose of gamma rays (40 Gy). There are many explanations for the stimulatory effects of low-dose of gamma radiation like Wi *et al.* (2005) who noted that there is a hypothesis that the low dose irradiation induces the growth stimulation by changing the hormonal signaling network in plant cells or by increasing the anti-oxidative capacity of the cells to overcome the daily stress factors easily such as fluctuations of light intensity and temperature in the growth condition. Similar enhancement effect on plant growth due to low dose of gamma radiation is in harmony with the results obtained by Minisi *et al*. (2013) on *Moluccella laevis* L plants. In contrast, by increasing radiation to high dose (80 Gy) a significant decrease in these characteristics were recorded during the two seasons. This reduction could be attributed to reduce in mitotic activity in meristematic tissues and reduced moisture content in seeds as reported by Khalil *et al*. (1986). Similarly, a reduction in plant height and number of branches for many crops that exposed to higher doses of gamma rays had already been reported by Sarada *et al*. (2015) on coriander plant.

The consequence in Table (2) showed that treating caraway plants with different levels of (P) fertilizer (0, 100, 150, 200 and 250kg/fed) grant the utmost significant rising in plant growth characteristics. With increasing the levels of (P) fertilizer up to 200 kg/fed the values of plant growth parameters recorded its peak.

These findings were recorded in both seasons. This could be attributed to the fact that (P) is required in large quantities in shoot tips where metabolism is high and cell division is rapid (Ndakidemi and Dakora, 2007). Also, the increasing in the

Table (2): Effect of different doses of gamma rays; phosphate fertilizer and their interactions on vegetative growth characteristics of caraway plants during two growing seasons.

P fertilizer (kg/fed) / Gamma dose (Gy)	First season (2012/2013)						Second season (2013/2014)					
	0	100	150	200	250	Mean	0	100	150	200	250	Mean
Plant height (cm)												
0	86.56	88.72	91.69	95.12	93.88	91.19	92.12	96.20	103.25	103.43	111.48	101.29
20	93.25	99.43	104.11	110.35	105.21	102.47	108.86	114.69	120.98	129.75	124.21	119.69
40	113.78	120.12	125.39	131.50	127.16	123.59	118.62	125.40	133.52	139.27	129.40	129.24
80	96.82	103.93	109.42	109.27	99.32	103.75	112.58	117.90	124.79	131.20	116.33	120.56
Mean	97.60	103.05	107.65	111.56	106.39		108.04	113.54	120.63	125.91	120.35	
L.S.D. at 5%	Gy= 5.23		P= 4.67		Gy × P= 10.41		Gy= 6.57		P= 5.33		Gy × P=11.88	
Number of main branches/plant												
0	6.25	6.72	6.99	7.51	7.28	6.95	7.60	7.81	8.40	9.01	8.66	8.29
20	7.46	8.11	8.84	9.37	8.75	8.50	9.10	9.64	10.31	10.85	10.72	10.12
40	9.18	10.21	10.57	11.26	10.80	10.40	10.61	11.25	11.88	12.49	11.57	11.56
80	7.85	7.99	8.15	8.92	8.34	8.25	8.71	9.18	9.80	10.02	9.73	9.48
Mean	7.68	8.25	8.63	9.26	8.79		9.00	9.47	10.09	10.59	10.17	
L.S.D. at 5%	Gy = 1.55		P= 1.24		Gy × P= 2.76		Gy= 2.05		P= 1.98		Gy × P= 4.14	
Fresh weight of whole plant (g/plant)												
0	154.07	163.15	168.27	179.45	174.24	167.83	167.25	172.41	178.62	186.54	180.87	177.13
20	176.70	181.89	193.46	204.52	197.18	190.75	191.25	199.67	208.62	217.17	201.42	203.62
40	198.37	211.39	218.88	226.15	220.09	214.97	209.91	217.00	229.28	234.75	222.64	222.71
80	165.40	179.95	189.55	197.60	182.93	183.08	186.02	191.42	198.36	211.29	205.68	198.55
Mean	173.63	184.09	192.54	201.93	193.61		188.60	195.12	203.72	212.43	202.65	
L.S.D. at 5%	Gy= 13.52		P= 11.65		Gy × P= 25.97		Gy= 16.32		P= 12.32		Gy × P= 26.76	

previous characters may be due to that (P) is known to help in developing a more extensive root system and thus enabling plants to extract water and nutrients from more depth. This trend is in harmony with previous results reported by (Awad Alla *et al*., 2013). They observed that the application of different levels of (P) increased the vegetative growth characteristics of coriander plants.

Referring to the interactions effect between different doses of gamma rays and (P) fertilizer levels, data in Table (2) reported that the growth characteristics of caraway plants were increased due to all tested combinations as compared with the control during two growing seasons. However, the combined treatment between gamma rays at (40 Gy) and (P) fertilizer at (200 kg/fed) induced the highest values of the measured growth characteristics during two seasons. These results are in agreement with the finding of Dar *et al*. (2015) on fenugreek plants.

2-Yield parameters

The data that pertaining to yield parameters of caraway plants expressed as number of umbels/plant, dry weight of umbels (g/plant) and fruit yield (g/plant and kg/fed) influenced by different doses of gamma irradiation have been presented in Table (3). Also, the result revealed that yield parameters progressively increased with increasing doses of gamma rays up to (40 Gy) in both seasons and then declined with further addition at (80 Gy). Moreover, rapid increase in yield parameters was observed between control and (20 Gy) and then remained constant or very slowly increased between (20 and 40 Gy) in most cases especially in the first season. Gamma rays are used for improving growth and quality of plants, for their high mutation frequency and they can interact with atoms and molecules. Thus, producing free radicals in cells affect the morphology, anatomy, biochemistry and physiology of the plants (Chahal and Gosal, 2002). These effects include change in plant cellular structure and metabolism, e.g. dilution of thylakoid membranes, alteration in photosynthesis, modulation of antioxidant system and accumulation of phenolic compounds (Kovacs and Keresztes, 2002; Kim *et al*., 2004 and Wi *et al*., 2005). These results are in agreement with those obtained by Datta (1997) on *Lantana depressa* and El-Khateeb *et al*. (2007) on *Melissa officinalis* whom mentioned that low dose of gamma rays that promoted the growth and the yield of these plants while a reduction in yield was happened by increasing gamma doses.

Mineral fertilization improves plant growth, development and yield by providing essential nutrients. For yield parameters, analysis of variance demonstrated significant results at level of 5% for most treatments as shown in Table (3). The results showed that plants which fertilized with different levels of (P) increased yield parameters as compared to the control. Maximum mean values of these parameters were recorded by using (P) fertilizer at (200 kg/fed) through the two seasons. This could be mainly attributed to the fact that (P) is an essential nutrient and an integral component of several important compounds in plant cells. These compounds include the carbon sugar phosphate involved in respiration, photosynthesis and the phospholipids of plant membranes, the nucleotides used in plant energy metabolism and in molecules of DNA and RNA (Taiz and Zeiger, 1991). Considering (P) as a constituent of cell nucleus, it is essential for cell division and development of meristematic tissue (Russell, 1973). Similar improvement effect of phosphorus fertilizer on yield was also reported by (Khalid, 2012) on anise, coriander and sweet fennel plants.

Table (3): Effect of different doses of gamma rays; phosphate fertilizer and their interactions on yield parameters of caraway plants during two growing seasons.

P fertilizer (kg/fed.) / Gamma doses (Gy)	First season (2012/2013)						Second season (2013/2014)					
	0	100	150	200	250	Mean	0	100	150	200	250)	Mean
Number of umbels												
0	32.52	36.46	39.81	42.50	42.12	38.68	37.30	40.82	43.11	47.26	42.24	42.14
20	38.76	44.21	49.90	50.88	46.65	46.08	41.07	48.35	50.46	54.68	51.92	49.29
40	42.37	48.29	51.12	55.56	47.90	49.04	47.11	54.00	59.80	60.31	52.16	54.67
80	40.22	41.93	45.16	45.28	43.49	43.21	44.25	44.62	47.38	46.75	42.64	45.12
Mean	38.46	42.72	46.49	48.55	45.04		42.43	46.94	50.18	52.25	47.24	
L.S.D. at 5%	Gy= 4.11		P= 3.56		Gy × P= 7.93		Gy= 5.27		P= 3.53		Gy × P= 7.87	
Dry weight of umbels												
0	25.16	27.26	30.45	32.69	28.95	28.90	29.72	31.62	38.89	39.90	35.16	35.05
20	31.40	32.52	35.67	38.29	36.05	34.78	36.21	40.38	41.69	44.51	39.18	40.39
40	33.11	36.60	38.91	41.35	37.45	37.48	38.60	42.26	45.03	48.17	43.80	43.57
80	29.63	31.74	32.00	36.90	30.32	32.11	31.77	33.18	40.38	40.67	38.26	36.85
Mean	29.82	32.03	34.25	37.30	33.19		34.07	36.86	41.49	43.31	39.10	
L.S.D. at 5%	Gy= 4.32		P= 4.64		Gy × P= 10.34		Gy= 5.81		P= 3.85		Gy × P= 8.58	
Fruit yield (g/plant)												
0	15.36	16.72	18.51	18.24	17.30	17.22	17.42	17.63	20.85	22.97	19.80	19.73
20	18.60	19.64	22.45	22.82	18.93	20.48	20.11	22.33	25.58	26.37	24.69	23.81
40	19.08	20.40	23.15	24.66	21.35	21.72	23.40	23.74	26.89	28.22	25.19	25.48
80	17.62	19.21	20.18	21.76	17.50	19.25	18.50	21.32	21.42	23.73	23.55	21.70
Mean	17.66	18.99	21.07	21.87	18.77		19.85	21.25	23.68	25.32	23.30	
L.S.D. at 5%	Gy= 1.64		P= 1.98		Gy × P= 4.21		Gy= 2.05		P= 2.31		Gy × P= 5.15	
Fruit yield (kg/fed)												
0	409.59	445.86	493.59	486.39	461.32	459.35	464.52	470.12	555.99	612.52	527.99	526.22
20	495.99	523.72	598.65	608.52	504.79	546.33	536.25	595.45	682.12	703.18	658.38	635.07
40	508.79	543.99	617.32	657.58	569.32	579.40	623.98	633.05	717.05	752.51	671.71	679.66
80	469.85	512.25	538.12	580.25	466.65	513.42	493.32	568.52	571.18	632.78	627.98	578.75
Mean	471.05	506.45	561.92	583.18	500.52		529.51	566.78	631.58	675.24	621.51	
L.S.D. at 5%	Gy= 1.63		P= 1.99		Gy × P= 4.22		Gy= 2.05		P= 2.30		Gy × P= 5.14	

Data tabulated in Table (3) illustrated that both different doses of gamma irradiation and (P) Fertilizer levels caused a corresponding increase in yield parameters. The application of using two factors under this study together were more effective for these parameters than the application of the individual factor. The highest improvement in the mean values of yield parameters were happened by using gamma rays at (40 Gy) plus (P) level at (200 kg/fed) in two growing seasons. These results pointed in the same direction of (Dar *et al*. 2015) on fenugreek plants.

3- Oil production

If the oil production of caraway plants is divided into 3 variables namely oil percentage, oil yield (cc/plant) and oil yield (l/fed.) as shown in Table (4), it may be noted that all variables showed great variation in the treated plants with different doses of gamma rays. Among different concentrations, higher dose of gamma rays (80 Gy) induced the highest oil content (%) while, exposing caraway seeds to pre-sowing gamma irradiation was beneficial at 40 Gy which markedly increased oil yield (cc/plant and l/fed.). This increase may be due to its simulative effect on fresh mass of umbels and seeds, as well as the activation of enzymes that involved in the metabolism of essential oil formation. Our results are supported by previous published studies that report an increase in oil production by gamma irradiation in several plant species like Youssef *et al*. (2000) on *Pelargonium graveolenus* and Zeid *et al*. (2001) on fennel plants.

It seems clear from Table (4) that phosphatic fertilization treatments led to significant differences in the essential oil content (%), where the plants treated with (P) fertilizer at (150 kg/fed) gave the highest content of volatile oil (%). Also, the highest oil yield (cc/plant and l/fed) were found by the addition of (P) fertilizer at (200 kg/fed) during the two growing seasons compared to unfertilized plants. (P) may have an impact on enzymes involved in the mevalonate pathway which are important in the biosynthesis of terpenes (Bruneton, 1999) and thus the essential oil seem to be affected by (P) fertilization (Kapoor *et al*., 2004). This finding in the present study is supported by Ughreja and Chundawat (1992) on coriander plants.

The aforementioned results reveal the interactions effect between different doses of gamma rays and (P) fertilizer levels on oil content which were esteem in Table (4). Furthermore, oil percentage (%) and oil yield (cc/plant and l/fed) of caraway plants were increased by using different combination treatments as compared to the control in the two growing seasons. Using gamma rays at (80 Gy) which interacted with (P) fertilizer at (150 kg/fed) produced the biggest content of essential oil. While the treatment of gamma rays at (40 Gy) + (P) fertilizer at (200 kg/fed) was the most important treatment for oil yield (cc/plant and l/fed) through the both seasons in comparison to the control and other combined treatments. Similar improvements were obtained by Nassar *et al.* (2004) on chamomile plants.

4-Photosynthetic pigments

The results in Table (5) revealed a significant effects of radiation doses on the contents of photosynthetic pigments (chlorophyll a, b and carotenoids, mg/g of fresh weight). All doses of gamma radiation increased the contents of photosynthetic pigments when compared with control. The highest contents of chlorophyll a, b and carotenoids were obtained by using gamma rays at (20, 40 and 80 Gy), respectively during the two growing seasons in comparison to the untreated seeds which give the lowest values in this issue. Gamma rays have been reported to affect differentially the

Table (4): Effect of different doses of gamma rays; phosphate fertilizer and their interactions on oil production of caraway plants during two growing seasons.

P fertilizer (kg/fed.) / Gamma doses (Gy)	First season (2012/2013)						Second season (2013/2014)					
	0	100	150	200	250	Mean	0	100	150	200	250	Mean
Oil (%)												
0	1.10	1.15	1.20	1.25	1.15	1.17	1.25	1.35	1.45	1.40	1.30	1.35
20	1.30	1.45	1.60	1.60	1.40	1.47	1.50	1.55	1.55	1.40	1.35	1.47
40	1.40	1.40	1.75	1.80	1.60	1.59	1.65	1.70	1.85	1.75	1.75	1.74
80	1.75	1.80	2.05	1.60	1.40	1.72	1.60	1.95	2.10	2.10	1.80	1.91
Mean	1.38	1.45	1.65	1.56	1.38		1.50	1.63	1.73	1.66	1.55	
L.S.D. at 5%	Gy= 0.33		P= 0.21		Gy × P= 0.46		Gy= 0.42		P= NS		Gy × P= 0.65	
Oil yield (cc/plant)												
0	0.17	0.19	0.22	0.23	0.20	0.20	0.22	0.24	0.30	0.32	0.26	0.27
20	0.24	0.28	0.36	0.37	0.27	0.30	0.30	0.35	0.40	0.37	0.33	0.35
40	0.27	0.29	0.41	0.44	0.34	0.35	0.39	0.40	0.50	0.50	0.44	0.45
80	0.31	0.35	0.41	0.35	0.25	0.33	0.30	0.42	0.45	0.50	0.42	0.42
Mean	0.25	0.28	0.35	0.35	0.27		0.30	0.35	0.41	0.42	0.36	
L.S.D. at 5%	Gy= NS		P= NS		Gy × P= NS		Gy= NS		P= NS		Gy × P= NS	
Oil yield (l/fed)												
0	4.51	5.13	5.92	6.08	5.31	5.39	5.81	6.35	8.06	8.58	6.86	7.13
20	6.45	7.59	9.58	9.74	7.07	8.09	8.04	9.23	10.57	9.84	8.89	9.31
40	7.12	7.62	10.80	11.84	9.11	9.30	10.30	10.76	13.27	13.17	11.75	11.85
80	8.22	9.22	11.03	9.28	6.53	8.86	7.89	11.09	11.99	13.28	11.30	11.11
Mean	6.58	7.39	9.33	9.24	7.00		8.01	9.36	10.97	11.22	9.70	
L.S.D. at 5%	Gy= 2.06		P= 1.84		Gy × P= 4.10		Gy= 3.51		P= 2.89		Gy × P= 6.44	

Table (5): Effect of different doses of gamma rays; phosphate fertilizer and their interactions on photosynthetic pigments of caraway plants during two growing seasons.

P fertilizer (kg/fed.) / Gamma doses (Gy)	First season (2012/2013)						Second season (2013/2014)					
	0	100	150	200	250	Mean	0	100	150	200	250	Mean
Chlorophyll A (mg/g fresh weight)												
0	4.91	5.13	5.49	5.51	5.26	5.26	4.62	4.75	5.12	5.05	4.91	4.89
20	6.32	6.85	7.19	7.03	6.80	6.83	5.63	5.90	6.20	6.39	5.71	5.96
40	6.25	6.44	6.39	6.28	5.99	6.27	6.11	6.22	6.00	5.88	5.41	5.92
80	5.28	5.29	6.11	6.18	5.76	5.72	5.84	6.07	5.91	6.30	5.13	5.85
Mean	5.69	5.92	6.29	6.25	5.95		5.55	5.73	5.80	5.90	5.29	
L.S.D. at 5%	Gy= 1.10		P= 1.02		Gy × P= 2.28		Gy= 0.88		P= NS		Gy × P= 1.21	
Chlorophyll B (mg/g fresh weight)												
0	2.02	2.10	2.07	1.97	1.85	2.00	1.85	1.96	1.94	2.11	2.14	2.00
20	2.30	2.61	2.56	2.89	2.60	2.59	2.67	2.95	3.27	3.33	3.42	3.12
40	2.92	3.03	3.61	3.25	2.82	3.12	3.15	3.28	3.41	3.76	3.11	3.34
80	2.57	2.48	2.73	2.75	2.81	2.66	2.40	2.37	2.52	2.85	2.31	2.49
Mean	2.45	2.55	2.74	2.71	2.52		2.51	2.64	2.78	3.01	2.74	
L.S.D. at 5%	Gy= 0.68		P= 0.43		Gy × P= 0.95		Gy= 0.92		P= 0.21		Gy × P=0.46	
Carotenoids (mg/g fresh weight)												
0	0.95	1.01	1.11	1.21	1.28	1.11	0.89	0.91	0.98	1.11	1.12	1.00
20	1.72	1.85	1.93	1.87	1.91	1.85	1.16	1.36	1.15	1.10	1.05	1.16
40	1.94	2.03	2.11	1.95	1.90	1.98	1.53	1.81	1.60	1.52	1.43	1.57
80	1.82	2.14	2.10	2.22	2.45	2.14	1.90	2.26	2.03	1.85	1.89	1.98
Mean	1.60	1.75	1.81	1.81	1.88		1.37	1.58	1.44	1.39	1.37	
L.S.D. at 5%	Gy= 0.55		P= NS		Gy × P= 0.66		Gy= 0.74		P= NS		Gy × P= 0.70	

morphology, anatomy, biochemistry and physiology that depending on the radiation levels. These effects included changes in plant cellular structure and metabolism, e. g. alteration in photosynthesis and consequently increased the values of photosynthetic pigments (Kim *et al*., 2004 and Wi *et al*., 2005). Also, related to the present study, the same findings were obtained by Said (2001) who found that exposing peppermint to different doses of gamma rays increased the values of chlorophyll a, b and carotenoids.

Data in Table (5) shows the response of photosynthetic pigments to (P) fertilizer at different levels. Addition of (P) fertilizer at the level of (150 kg/fed) was the best treatment for the contents of chlorophyll a and chlorophyll b in the first season while using the level of (200 kg/fed) produced the highest contents of chlorophyll a and chlorophyll b during the second season. As for the highest increment in carotenoids content was observed by using (P) fertilizer at the levels of 250 and 100 kg/fed for the first and second seasons, respectively. This improvement may be due to phosphorus as it is also a necessary nutrient for the biosynthesis of chlorophyll, where (P) as pyridoxal phosphate must be present for the biosynthesis of chlorophyll (Ambrose and Easty, 1977). These results pointed in the same direction of Nyoki and Patrick (2014) on cowpea plants which reported that supplementation of phosphorus at all levels significantly increased the chlorophyll content.

With respect to photosynthetic pigments as influenced by different integration treatments between the two factors under this study, it is evident from data tabulated in Table (5) that using gamma rays at the low dose (20 Gy) + each of (P) fertilizer at (150 or 200 kg/fed) produced the maximum content of chlorophyll (a) in the first and second seasons, respectively. Moreover, it could be mentioned that, the highest value of chlorophyll (b) was happened by exposing seeds to the moderate dose of gamma rays (40 Gy) and fertilized by (P) levels at each of (150 or 200 kg/fed) through the first and second seasons, respectively. Finally, the highest content of carotenoids was done by the application of high gamma dose (80 Gy) plus each of (250 or 100 kg/fed) of (P) fertilizer during the first and second seasons, respectively.

5-Some macronutrients, crude protein and total carbohydrate content (%)

Plant growth and the accumulation of N, P, K, crude protein and total carbohydrate (%) were considered to be the most important factors related to the specific effect of gamma rays as found in Table (6). Generally, these percentages were improved in plant samples that produced from seeds which treated by gamma radiation. The highest concentrations (%) of (N) and crude protein were mostly achieved with gamma rays at (20 Gy), while the highest (P) and total carbohydrate contents were found by using gamma rays at (40 Gy). Also, the application of gamma rays at (80 Gy) produced the greatest enhancement in (K) content (%) compared with those of un-irradiated treatments during two growing seasons. The stimulating effect of gamma rays on nutrients and total carbohydrate contents were reported by Deaf (2000) on lemongrass and Mahmoud (2002) on delphinium plants.

The contents (%) of some macronutrients (N, P and K), crude protein and total carbohydrate values of dry caraway plants as affected by the

Table (6): Effect of different doses of gamma rays; phosphate fertilizer and their interactions on nitrogen, crude protein, phosphorus, potassium and total carbohydrate content (%) of caraway plants during two growing seasons.

P fertilizer (kg/fed.) / Gamma doses (Gy)	First season (2012/2013)						Second season (2013/2014)					
	0	100	150	200	250	Mean	0	100	150	200	250	Mean
N (%)												
0	2.52	2.91	3.31	3.16	2.86	2.95	2.18	2.31	2.84	2.86	2.50	2.53
20	3.18	3.35	3.69	3.42	3.30	3.38	2.95	3.12	3.58	3.47	3.27	3.27
40	3.25	3.19	3.57	3.50	3.28	3.35	2.95	3.06	3.29	3.31	3.16	3.15
80	2.93	2.89	3.00	3.02	2.95	2.95	2.71	2.66	2.85	2.88	2.56	2.73
Mean	2.97	3.08	3.39	3.27	3.09		2.69	2.78	3.14	3.13	2.87	
L.S.D. at 5%	Gy= 0.24		P= 0.21		Gy × P= 0.46		Gy= 0.52		P= 0.39		Gy × P= 0.86	
Crude protein (%)												
0	14.49	16.73	19.03	18.17	16.45	16.97	12.54	13.28	16.33	16.45	14.38	14.60
20	18.29	19.26	21.22	19.67	18.98	19.48	16.96	17.94	20.59	19.95	18.80	18.85
40	18.69	18.34	20.53	20.13	18.86	19.31	16.96	17.60	18.92	19.03	18.17	18.14
80	16.85	16.62	17.25	17.37	16.96	17.01	15.58	15.30	16.39	16.56	14.72	15.71
Mean	17.08	17.74	19.51	18.84	17.81		15.51	16.03	18.06	18.00	16.52	
L.S.D. at 5%	Gy= 1.38		P= 1.21		Gy × P= 2.64		Gy= 2.99		P= 2.24		Gy × P= 4.94	
P (%)												
0	0.25	0.33	0.36	0.37	0.31	0.32	0.23	0.21	0.26	0.26	0.27	0.24
20	0.32	0.36	0.40	0.44	0.39	0.38	0.29	0.34	0.38	0.36	0.31	0.33
40	0.37	0.35	0.42	0.48	0.44	0.41	0.34	0.42	0.41	0.45	0.38	0.40
80	0.29	0.29	0.41	0.38	0.33	0.34	0.30	0.28	0.33	0.37	0.32	0.32
Mean	0.30	0.33	0.39	0.41	0.36		0.29	0.31	0.34	0.36	0.32	
L.S.D. at 5%	Gy= NS		P= 0.12		Gy × P= NS		Gy= 0.11		P= NS		Gy × P= NS	
K (%)												
0	2.75	3.11	3.30	3.42	3.39	3.19	2.59	2.61	2.88	3.20	3.35	2.92
20	2.96	3.25	3.46	3.50	3.61	3.35	3.20	3.20	3.41	3.71	3.68	3.44
40	3.44	3.75	3.69	3.81	3.62	3.66	3.52	3.61	3.73	3.81	3.84	3.70
80	3.58	3.55	3.83	3.79	3.92	3.73	3.64	3.77	3.83	3.89	3.89	3.80
Mean	3.18	3.41	3.57	3.63	3.63		3.23	3.29	3.46	3.65	3.69	
L.S.D. at 5%	Gy= 0.18		P= 0.20		Gy × P= 0.44		Gy= 0.31		P= 0.23		Gy × P= 0.51	
Total carbohydrate (%)												
0	11.64	11.93	12.11	12.37	12.89	12.18	12.15	12.32	12.60	12.53	12.48	12.41
20	12.95	13.11	13.42	13.30	13.68	13.29	13.62	13.45	13.75	13.77	13.91	13.70
40	13.80	14.53	14.88	15.13	15.40	14.74	13.76	13.85	14.61	14.95	15.31	14.49
80	13.11	13.28	13.15	13.40	14.17	13.42	12.60	12.61	13.18	14.72	14.65	13.55
Mean	12.87	13.21	13.39	13.55	14.03		13.03	13.05	13.53	13.99	14.08	
L.S.D. at 5%	Gy= 1.87		P= 1.46		Gy × P= 3.25		Gy= 1.28		P= 1.31		Gy × P= 2.92	

treatments of 4 phosphorus levels plus unfertilized plants are reported in Table (6). The maximum contents of (N, P and K) were produced by the application of (P) fertilizer at rates of (150, 200 and 250 kg/fed), respectively. While using (P) fertilizer at the rates of (150 and 250 kg/fed) produced the highest crude protein and total carbohydrate values of dry caraway plants, respectively during both seasons. These results may be due to the beneficial effect of phosphorus on metabolic processes and growth which positively reflected on chemical constituents of caraway plants. The acquired results are confirmed with those reported by Ahmed and El-Abagy (2007) on faba bean plants.

Among all interaction treatments which induced remarkable increments in the contents of some macronutrients (N, P and K), crude protein and total carbohydrate (%) as in (Table, 6) where their maximum contents of N, crude protein, P, K and total carbohydrate were found in plants which treated by (20 Gy + 150 kg P fertilizer/fed), (20 Gy + 150 kg P fertilizer/fed), (40 Gy + 200 kg P fertilizer/fed), (80 Gy + 250 kg P fertilizer/fed) and (40 Gy + 250 kg P fertilizer/fed), respectively during both seasons.

Finally, the present study recommended that the application of gamma rays at (40 Gy) which combined with (P) fertilizer at the rate of (200 kg/fed) had a beneficial effect on vegetative growth characters, yield parameters and oil production of caraway plants during two seasons.

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تأثير أشعة جاما و التسميد الفوسفاتي علي النمو والمحصول و التركيب الكيماوي لنباتات الكراوية

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الملخص العربي:

حديثاً تُستخدم تكنولوجيا الإشعاع علي نطاق واسع لإحداث تغيرات في صفات النبات تؤدي إلي تحسين و تطوير هذا المنتج النباتي. من أجل هذا أُجريت تجربة حقلية علي الأرض الطينية الرسوبية في المزرعة التجريبية لكلية الزراعة – جامعة المنوفية – شبين الكوم – مصر (٣٠,٥٢ ° شمالاً و ٣٠,٩٩ ° شرقاً) خلال موسمي نمو شتاء متتاليين ٢٠١٢/٢٠١٣ و ٢٠١٣/٢٠١٤ م علي نبات الكراوية و ذلك لتقييم كلٍ من الأثر الفردي و المشترك لجرعات مختلفة من أشعة جاما (صفر، ٢٠، ٤٠ و ٨٠ جراي) و مستويات مختلفة من التسميد الفوسفاتي (صفر، ٥٠، ٧٥، ١٠٠ و ١٢٥ ٪ من الجرعة الموصي بها و التي تساوي صفر، ١٠٠، ١٥٠، ٢٠٠ و ٢٥٠ كجم / فدان من سماد السوبر فوسفات الشائع و الذي يحتوي علي فو٢أ٥ = ١٥,٥ ٪) وذلك علي كلٍ من محصول نبات الكراوية و مكوناته. و قد صُممت التجربة بنظام قطع منشقة في ثلاث مكررات.

وأشارت النتائج إلي أن إستخدام الإشعاع بواسطة أشعة جاما سواءً منفرداً أو متحداً مع التسميد الفوسفاتي أدي إلي زيادة معنوية في كل مقاييس النمو الخضري مثل إرتفاع النبات (سم)، عدد الافرع الرئيسية / نبات ، الوزن الطازج للنبات (جم) و كذلك مقاييس المحصول مثل عدد النورات الخيمية / نبات ، الوزن الجاف للنورات الخيمية (جم / نبات) و أيضاً محصول الثمار (جم / نبات أو كجم / فدان) و أخيراً المحتوي من صبغات البناء الضوئي (مجم / جم وزن طازج) ، المحتوي (٪) من كلٍ من الزيت الطيار و النيتروجين و الفوسفور و البوتاسيوم و البروتين المحسوب و الكربوهيدرات الكلية وذلك في نباتات الكراوية. وقد سُجلت أكبر زيادة في معظم مقاييس النمو الخضري و المقاييس المحصولية و (٪) للزيت و المحتوي (٪) من الفوسفور في المعاملة المتحدة لأشعة جاما بجرعة ٤٠ جراي + إضافة السماد الفوسفاتي بمعدل ٢٠٠ كجم / فدان. بينما كانت أكبر زيادة في الكاروتينددات مصاحبة للمعاملة أشعة جاما بجرعة ٨٠ جراي + إضافة السماد الفوسفاتي بمعدل ٢٥٠ كجم / فدان. وأيضاً أوضحت النتائج أن أكبر زيادة في المحتوي من الكربوهيدرات الكلية (٪) كان مصاحباً للمعاملة بأشعة جاما بجرعة ٤٠ جراي + إضافة السماد الفوسفاتي بمعدل ٢٥٠ كجم / فدان. وأخيراً فإن الجرعة المنخفضة من الإشعاع (٢٠ جراي) + السماد الفوسفاتي بمعدلي ١٥٠ او ٢٠٠ كجم / فدان أعطي أكبر قيمة لكلوروفيل أ وذلك في موسمي النمو الأول و الثاني علي التوالي. بينما وجد أن أعلي قيمة لكلوروفيل ب كانت مصاحبة لمعاملة الإشعاع بجرعة ٤٠ جراي + السماد الفوسفاتي بمعدلي ١٥٠ او ٢٠٠ كجم / فدان وذلك في موسمي النمو الأول و الثاني علي التوالي.

وطبقاً للنتائج المتحصل عليها، وفي ظل الظروف المصرية، فإن هذه الدراسة توصي بأنه يجب الإهتمام بمعاملة البذور بأشعة جاما بهدف تحسين صفات البذورمع إضافة السماد الفوسفاتي لما له من دور كبير في تحسين خواص التربة و زيادة خصوبتها و بالتالي زيادة إنتاجية نبات الكراوية.

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