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Stimulate Common Bean (*Phaseolus Vulgaris* L.) Productivity Based on Seed Irradiation and Foliar Application of Zinc

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COMMON bean is an important vegetable crop grown in Egypt for local consumption and can be exported abroad. Its dry seeds are valuable sources of protein. To increase its productivity, common bean seeds were irradiated when it was exposed to ionizing radiation (gamma irradiation) for a predetermined amount of time that depends on the radioactivity of the radioactive source (^{60}Co). Worldwide, billions of people suffer from zinc (Zn) insufficiency. Zinc is an essential mineral for plants and mammals. This study aimed to evaluate the effects of foliar Zn sprays and seeds gamma irradiation on the growth, yield, productivity and grain nutritional quality of common bean. The experimental design was a split-plot in two factors with three replicates. The main plots were seeds gamma irradiation (0, 10, 20, and 80 Gy) and the sub-plots were zinc spraying as $ZnSO_4$ (0, 50, 100 and 150 mg L^{-1}). Field experiments were carried out in two successive growing seasons under field conditions using drip irrigation system. One commercial common bean cultivar was used (Bronco). Some of growth parameters yield and quality parameters were estimated to follow the effect of zinc fertilization and gamma irradiation on the common bean plant. The results indicated that increasing Zn concentration in the spray solution cased a positive in common bean. Also Exposing seeds to moderate doses of gamma rays leads to positive effects on plant growth, yield and quality. In this regard, it was concluded that there was a positive interaction between spraying with zinc and gamma irradiation.

Keywords*:* Common bean; Ionizing radiation; Zinc; foliar spray; Uptake.

1. Introduction

The common bean plant is one of most significant vegetable crops in Egypt, both for domestic consumption and for export. The statistics of the Egyptian Ministry of Agriculture in 2022 showed that, with an average yield of 3.18 Mg, the 116.76 ha of green common bean production produced roughly 371.41 Mg **(MALR, 2022)**. For millions of individuals, it serves as a most efficient source of dietary fibre, calories, proteins, minerals, and vitamins, among other critical nutrients (**Abdel-hakim *et al.*, 2012)**. Green bean pods and seeds are rich in protein, calcium, iron, thiamine, fat, fibre, and carbohydrates **(Abebe *et al.*, 2019).** Fasoulia, a common bean in Egypt, is part of the Leguminaceae family **(Singh *et al.*, 2013)**. Common beans are picked and eaten, while their pods are closed, usually before the seeds have had time to fully develop **(Acosta-Diaz *et al.*, 2015)**.

Zinc is an essential element of the metabolism of carbohydrates. It activates most of the enzymes involved in this process **(Maret, 2019)**. Furthermore, zinc activates the enzymes carbonic anhydrase, fructose-1,6-biphosphate, and aldolase **(Tavakoli *et al.*, 2014)**. These enzymes reduced activity in the presence of zinc a deficit leads to the formation of carbohydrates in plant leaves **(Mousavi, 2011)**. As a co-factor in several enzymes in biochemical pathways primarily involved in the metabolism of carbohydrates during photosynthesis and the conversion of sugar to starch, auxin growth regulators, preservation of membrane integrity, protein synthesis, pollen formation and nucleic acid synthesis, zinc plays a significant role **(Alloway, 2008)**. Application of zinc also boosted mung bean chlorophyll concentrations, crude protein content and plant development **(Samreen *et al.*, 2017)**. Zinc deficiency (49%) in soil is a worldwide nutritional problem in crop production. The variance in the soils ability

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to adsorb zinc was identified as the cause of the zinc use efficiency (ZUE) of less than 3.5% **(Maqbool and Beshir, 2018)**.

Because they may both easily pass through living objects, gamma rays and X-rays are comparable in several ways **(Lima *et al.*, 2011)**. Gamma rays have enough energy to ionize matter and thus can damage living cell **(Wi *et al.*, 2005)**. They are considered the most penetrating radiation compared to other sources such as alpha and beta rays **(Jan, 2012)**. Gamma rays belong to ionizing radiation and react with atom or molecules to produce free radicals in the cell **(Hong *et al.*, 2022)**. Depending on the amount of irradiation, these radicals have been shown to have an impact on the morphology, biochemistry, anatomy and physiology of plants. They may alter or damage critical components of plant cells in cases of high radiations or for prolong time periods **(Rahimi and Bahrani, 2011)**. On the other hand, plants exposed to comparatively low levels of gamma radiation showed signs of increased enzyme activity, cell development, germination rate and crop yield **(El-Beltagi *et al.*, 2011)**. **Soliman and Abd-El-Hamid (2003)** found that number of leaves, number of branches, shoot length and leaves area of Kidney bean (*Phaseolus vulgaris* L. Cv. Giza 6) significantly increased in response to gamma irradiation of the seeds with 25 and 50 Gy compared with the control treatment. **Hussein (2010)** also confirmed that gamma radiation doses (50-100 Gy) increased total protein contents in mug bean. Irradiated pea plant seeds with 10 Gy of gamma rays gave the highest significant values for plant height, number of leaves, number of branches per plant and seed protein content **(El-Ghareeb, 2006)**.

Therefore, this study aims at (i) studying the effect of gamma irradiation of seeds at low doses to stimulate their growth together with foliar application with zinc on increasing common bean plants, growth, yield and productivity (ii) and improving plant growth and yield via seed irradiation and zinc spray.

2. Materials and Methods

2.1 Materials

The present work was completed throughout the course of two consecutive seasons of 2020/2021 and 2021/2022 in the experimental field of Plant Research Department, Nuclear Research Center (NRC), Egyptian Atomic Energy Authority (EAEA), Inshas, Egypt to study growth, yield and productivity of common bean Cv. Bronco under five different doses of radiation i.e. 0, 10, 20, 40 and 80 Gray (Gy) using ^{60}Co Gamma source at Cyclotron project, NRC, EAEA and spraying with four concentrations of zinc sulphate ($Znso_4$) i.e. 0, 50, 100 and 150 mg L^{-1} which were sprayed after 30 days from planting. This foliar application was conducted in the morning time using a hand pressure sprayer, the irrigation system used was drip irrigation. Soil physical and chemical analyses are presented in Table 1.

Table 1. Properties of the soil used in the study.

Parameter	Season	
	2020/2021	**2021/2022**
Sand (%)	88.0	88.1
Clay (%)	4.6	4.8
Silt (%)	7.4	7.1
Soil texture	Sand	Sand
PH*	7.4	7.5
Organic matter (g kg^{-1})	19.0	19.0
EC (dS m^{-1})	0.89	0.91
Av. N (mg kg^{-1})	34.0	40.0
Av. P (mg kg^{-1})	9.5	10.3
Av. K (mg kg^{-1})	135.0	141.0
Zn (mg kg^{-1})	0.32	0.40

Soil pH in soil water suspension 1:2.5 (w/v)

Methods of soil sampling and analysis that were followed in this study were reported in **Cavalli *et al.* (2014)**. The experimental design was split-plot in two factors with three replicates. Concentrations of zinc were assigned in the main-plots and doses of radiation were randomly distributed in sub-plots. Each plot area was 12 m^2 (2.40 m width × 5 m length). The plot contains five ridges and the distance between them was 40 cm. Common bean seeds were hand sown directly after irradiation in 27th and 29th September in the first and second seasons, respectively on one side of drip irrigated in hills spaced 10 cm apart, 3-seed per hill at 3-4 cm depth.

All plots received the recommended rate (by Ministry of Agriculture and Land Reclamation) of nitrogen (144.3 kg ha^{-1}) as $(NH4)_2SO_4$, Phosphorus (32.2 kg ha^{-1}) as P (mono calcium phosphate), potassium (47.4 kg ha^{-1}) as K (K_2SO_4). P and K fertilizers were added before sowing and soil preparations process. On the other hand, nitrogen fertilizer was added in five equal splits, the first was before sowing then after 2, 5, 8 and 11 weeks of planting throw the irrigation system. Other micronutrients were sprayed as recommended rate according to Ministry of Agriculture and Land Reclamation (Iron at 476 g ha^{-1} (as Ferrous sulfate), and Manganese and Copper at 238 g ha^{-1} (as Sulphate form) were sprayed two times every 15 days from the beginning of flowering.

2.2 Methods of analysis

2.2.1 Green measurements

At 60 days after planting, ten randomly selected samples of each experimental unit of plants were counted. Data were recorded about the number of leaves, branches, green pods per plant, germination percentage (%), plant height (cm) and leaf area (cm^2). In accordance with **(Koller, 1972)**, leaf area was computed as the relationship between unit area and leaf weight as follows:

$$\text{Leaf area } (cm^2) = \frac{\text{Disks area x No. of disks x leaf fresh weight}}{\text{Disks fresh weight}}$$

Also, total chlorophyll was estimated using SPAD (model MINOLTA) in the field at the vegetative growth stage.

2.2.2 Pod yield and its components

To assess the yield and its components, including pod yield (Mg ha^{-1} = 1000 kg ha^{-1}), green pods were collected at maturity from each plot.

2.2.3 Chemical analysis in leaves

According to **Estefan *et al.* (2013)**, common bean pods after collection were oven dried at 70^oC and then digested using hydrogen peroxide solution and sulphuric acid (H_2SO_4). Nitrogen was determined using Kjeldahl method according to **Jones *et al.* (1991)**. Also, potassium was estimated using flame photometer JENWAY Model PFP7, phosphorus was determined using UV-spectrophotometer GENWAY Model 6405 and zinc were determined using atomic absorption spectrometry model shimadzo 6800. The total N was multiplied by 6.25 to determine the protein content of dried pods **(Kelly and Bliss, 1975)**. In addition, total sugar in dry pods was determined calorimetrically using phenol-sulphuric acid methods according to **Dubois *et al.* (1956)** using spectrophotometer model Shimadzo UV-1601.

2.3 Statistical analyses

All data were analyzed by two-way analyses of variance (ANOVA) in a split-plot design **(Saranya, 2024)** using SPSS software version 20. The treatment means were compared using Duncan for the main effects as well as their interactions at P=0.05 level. All graphs were drawing using Origin pro software version 2024.

3. Results

3.1 Germination percent, plant height and pod length

Zn application rates and gamma irradiation doses had substantial impacts on the following plant characters: seed germination, plant height and pod length (Fig. 1). Germination of seeds which were exposed to either 10 or 20 Gy, although they nearly closed to each other, tended to increase over those exposed to 40 and 80 Gy dose. This trend was occurred in plant height and pod length. It is worthy that 80 Gy resulted in reduction of seed germination percent, plant height and pod length comparable to other doses or the non-irradiated ones. It seems that this dose, to some extent, inhibited the seed germination percent, plant height and pod length. Slight differences in seed germination percent, plant height and pod length were detected between the two growing seasons. With respect to the effect of Zn dose, germination percent, plant height and pod length were gradually increased with increasing Zn rate up to 150 mg L^{-1}. Values recorded at 100 and 150 mg Zn L^{-1} were nearly closed to each other in germination percent. Similarly, slight differences were observed for both growing seasons. This phenomenon was proved by the interaction of gamma irradiation doses and zinc application rates where the germination percentages, plant height and pod length were improved upon exposure to 10 Gy and supplement with 150 mg Zn L^{-1} (Table 2).

Despite of irradiation dose, the overall means of germination percent, plant height and pod length were gradually increased with increasing Zn levels without significant difference under each growing season (in germination percent only). In this respect, the germination percent was not reflect any significant differences between 100 and 150 mg Zn L^{-1}. This was true for both growing seasons.

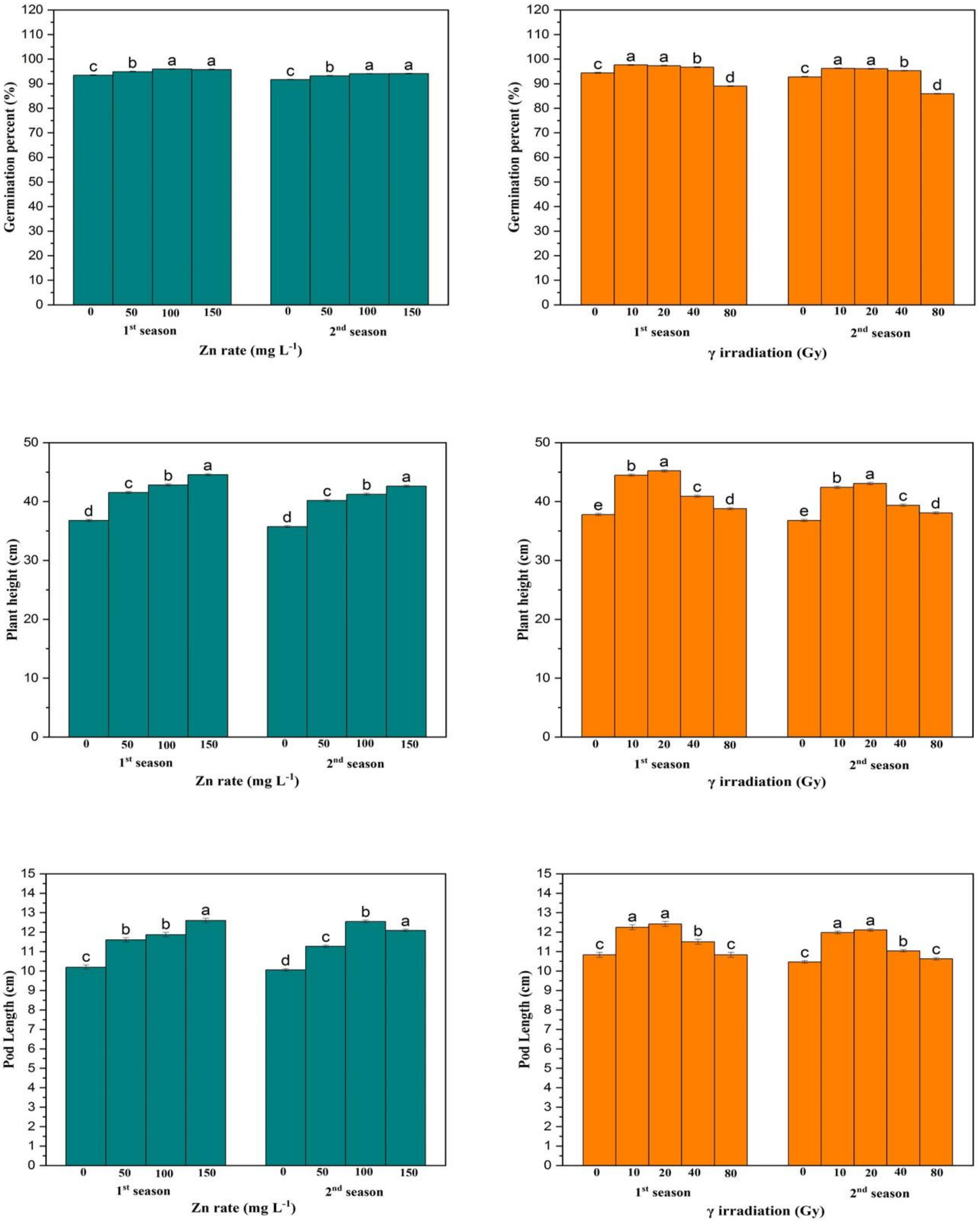

Fig. 1. Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on germination percent, plant height and pod length. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

Table 2. Interaction effect of gamma irradiation and zinc spray on germination percent, plant height and pod length.

Treatments	Germination percent (%)		Plant height (cm)		Pod Length (cm)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zn_0R_0	92.3j	90.3i	36.6mno	35.7nop	10.7ghi	10.3mnop
Zn_0R_{10}	96.5defg	95.0defg	37.0lmno	36.0mnop	10.3hi	10.2nop
Zn_0R_{20}	96.2efgh	94.8efg	37.6klmn	36.4lmno	10.0i	10.1op
Zn_0R_{40}	95.9fgh	94.5fgh	36.5no	35.4op	10.0i	10.0p
Zn_0R_{80}	86.4m	83.7n	36.2o	35.1p	10.0i	9.9p
$Zn_{50}R_0$	94.5j	93.0i	37.8klm	36.8lmn	10.7ghi	10.4lmno
$Zn_{50}R_{10}$	97.5abcd	96.3abc	45.2d	43.2de	12.3cd	12.2de
$Zn_{50}R_{20}$	97.4bcde	96.0abcd	44.3de	42.3ef	12.3cd	11.9ef
$Zn_{50}R_{40}$	96.7cdef	95.2def	41.4g	40.1hi	11.7def	11.2hi
$Zn_{50}R_{80}$	88.4l	85.5m	39.1hij	38.5ik	11.0fgh	10.7jkl
$Zn_{100}R_0$	95.5ghi	94.0gh	38.1jkl	37.1lm	11.0fgh	10.5klmn
$Zn_{100}R_{10}$	98.6a	97.0a	46.4c	44.1cd	12.7c	12.4cd
$Zn_{100}R_{20}$	98.1ab	96.9ab	47.5c	45.2c	12.7c	12.6c
$Zn_{100}R_{40}$	97.2bcde	95.9bcd	42.4fg	40.5gh	12.0cde	11.4gh
$Zn_{100}R_{80}$	90.3k	86.6l	39.7hi	39.2ij	11.0fgh	10.9ijk
$Zn_{150}R_0$	95.3hi	93.8hi	38.6ijk	37.6kl	11.0fgh	10.7jklm
$Zn_{150}R_{10}$	97.9abc	96.7ab	49.3b	46.3b	13.7b	13.3b
$Zn_{150}R_{20}$	97.7abc	96.6abc	51.4a	48.3a	14.7a	13.9a
$Zn_{150}R_{40}$	97.0bcdef	95.5cde	43.3ef	41.4fg	12.3cd	11.6fg
$Zn_{150}R_{80}$	91.0k	87.9k	40.1h	39.5hij	11.3efg	11.0hij

Notes: Zn_0, Zn_{50}, Zn_{100} and Zn_{150} mean 0, 50, 100 and 150 mg L^{-1} of zinc sulphate, respectively and R_0, R_{10}, R_{20}, R_{40} and R_{80} mean 0, 10, 20, 40 and 80 Gy of gamma irradiation, respectively. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

3.2 Number of both of leaves, branches and green pods per plant

Number of leaves, number of branches and number of green pods per plant were significantly raising by increasing the rate of Zn. on the other hand, gamma doses at 10 and 20 Gy gave a significantly higher effect over 40 and 80 Gy. The least values of number of leaves, branches and green pods per plant were recorded for both plants that received 80 Gy as well as the control plants with no significant variations among these two treatments during the two growing seasons (Fig. 2). With respect to the effect of Zn rates, number of leaves, branches and green pods were gradually increased with increasing Zn rate up to 150 mg L^{-1}. In this concern, values recorded for application of 150 mg Zn L^{-1} were the highest within the two growing seasons. This observation was confirmed by noticing the interaction effects of gamma irradiation doses and zinc application rates where the number of leaves, branches and green pods were all improved when seeds exposed to 10, 20 Gy and supplemented with 150 mg Zn L^{-1} (Table 3). The combinations of Zn and gamma irradiation led to concurrent increase the number of leaves, branches and green pods per plant. However, increasing Zn rate leads to increase number of leaves, branches and green pods per plant, while raising gamma dose over 20 Gy induced a negative effect on number of leaves, branches and green pods per plant. The interaction between Zn rate at 150 mg L^{-1} and gamma irradiation at 20 Gy dose resulted in the highest values of number of leaves, branches and green pods per plant.

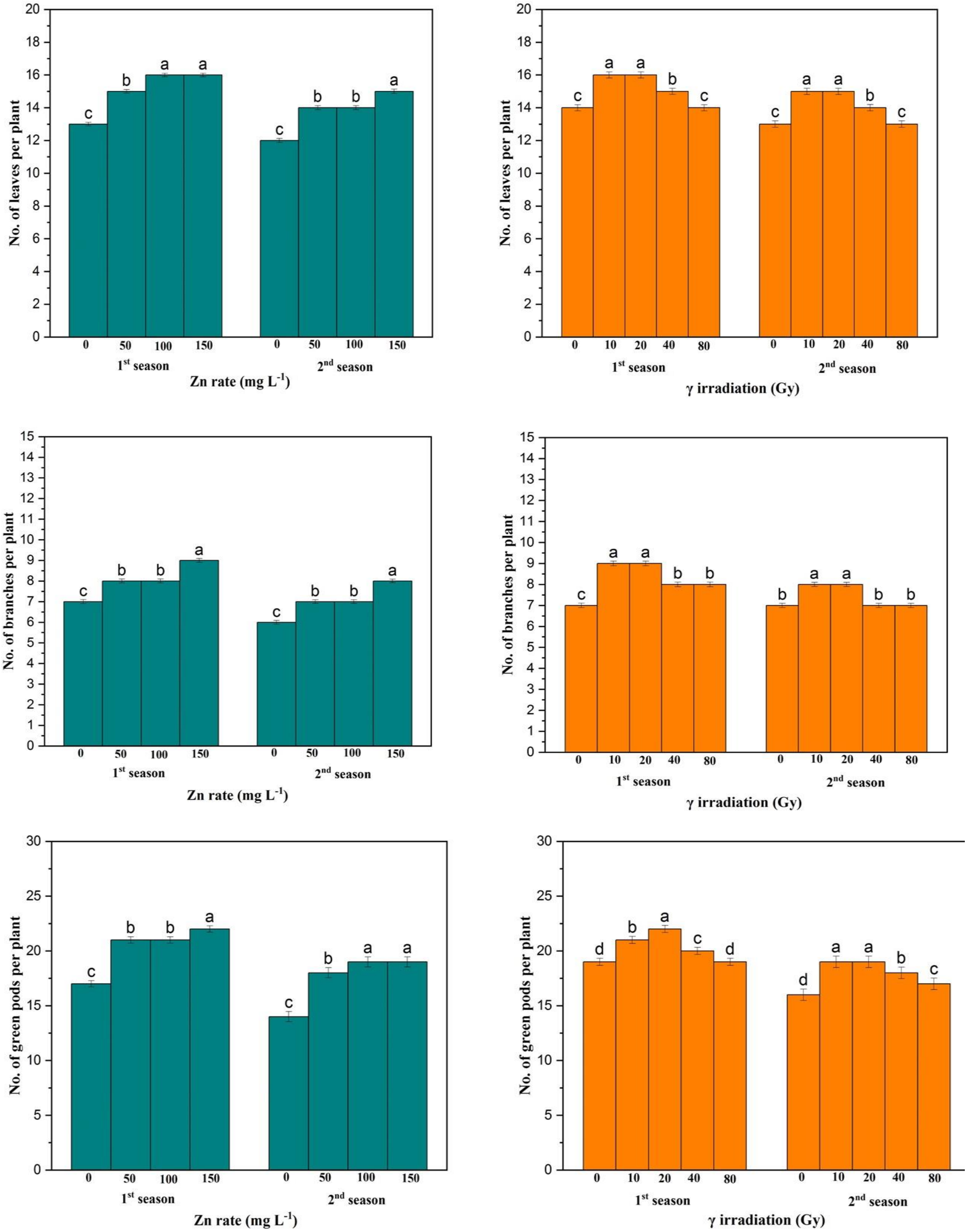

Fig. 2. Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on number of both of leaves, branches and green pods per plant. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

Table 3. Interaction effect of gamma irradiation and zinc spray on Number of leaves per plant, Number of branches per plant and Number of green pods per plant.

Treatments	No. of leaves plant^{-1}		No. of branches plant^{-1}		No. of green pods plant^{-1}	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zn_0R_0	14e	12f	7d	6d	17h	10i
Zn_0R_{10}	14e	13e	7d	6d	18g	15f
Zn_0R_{20}	14e	13e	7d	6d	19f	15f
Zn_0R_{40}	13f	12f	7d	6d	17h	14g
Zn_0R_{80}	13f	11g	7d	6d	16i	13h
$Zn_{50}R_0$	14e	13e	7d	6d	20c	17e
$Zn_{50}R_{10}$	16c	15c	9b	8b	22c	19c
$Zn_{50}R_{20}$	16c	15c	9b	8b	21d	19c
$Zn_{50}R_{40}$	15d	14d	8c	7c	21d	19c
$Zn_{50}R_{80}$	14e	13e	8c	7c	20e	18b
$Zn_{100}R_0$	14e	13e	7d	7c	20c	17e
$Zn_{100}R_{10}$	17b	15c	9b	8b	22c	20b
$Zn_{100}R_{20}$	17b	16b	9b	8b	23b	20b
$Zn_{100}R_{40}$	15d	14d	8c	7c	21d	19c
$Zn_{100}R_{80}$	15d	14d	8c	7c	21d	18d
$Zn_{150}R_0$	14e	13e	8c	7c	20c	18d
$Zn_{150}R_{10}$	18a	16b	10a	9a	23b	21a
$Zn_{150}R_{20}$	18a	17a	10a	9a	24a	21a
$Zn_{150}R_{40}$	15d	14d	8c	8c	21d	19c
$Zn_{150}R_{80}$	15d	14d	8c	7c	21d	18d

See Table 2 foot notes. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

3.3 Leave area and total chlorophyll

Leave area was significantly increased by increasing the rate of Zn. On the other hand, gamma doses at 10 and 20 Gy were more effective than 40 and 80 Gy (Fig 3). Regarding the effect of gamma irradiation, 40 Gy dose scored the highest leaf area in both seasons.

Leave area tended to increase gradually with increasing Zn rate up to 150 mg L^{-1}. Values recorded at 150 mg Zn L^{-1} were the in the two seasons of study. The data did not show any discernible variations between the effects of gamma and zinc irradiation on total chlorophyll. As a result, applying a zinc spray causes an increase in total chlorophyll and leaf area. Both the leaf area and the total chlorophyll content increased with gamma doses of 10 and 20 Gy. Regarding the interaction impact of gamma irradiation doses and zinc rates, it was found that raising zinc rates enhanced leaf area even in the presence of gamma irradiation doses (Table 4). Adversely, 80 Gy (R_{80}) led to reductions in the leave area and total chlorophyll, especially in the absence of spraying with zinc (Zn_0).

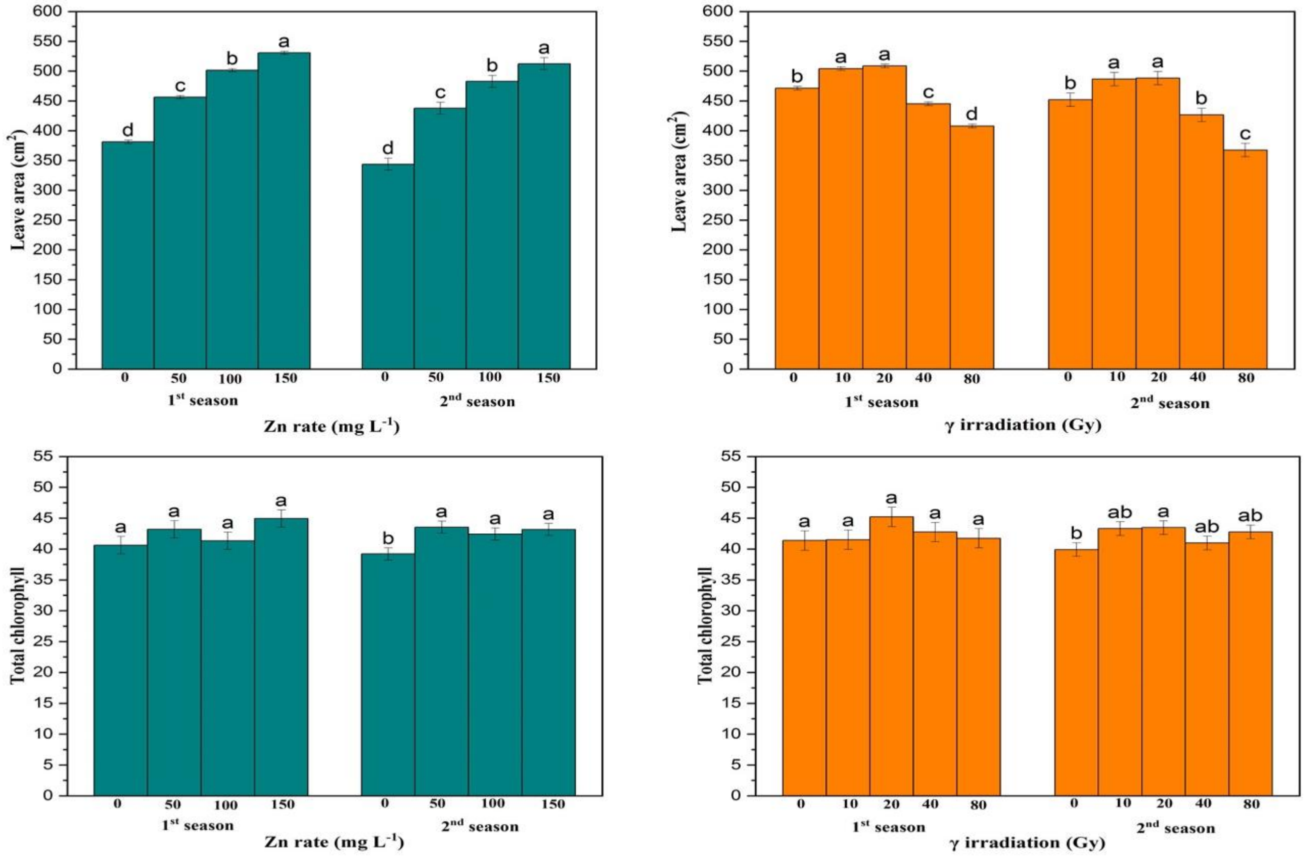

Fig. 3. Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on leave area and total chlorophyll. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

Table 4. Interaction effect of gamma irradiation and zinc spray on leave area and total chlorophyll

Treatments	Leave area (cm^2)		Total chlorophyll	
	1st season	2nd season	1st season	2nd season
Zn_0R_0	381opq	359j	40.6ab	39.2bc
Zn_0R_{10}	389nop	379ij	41.0ab	39.4bc
Zn_0R_{20}	398mno	384ij	41.2ab	39.7bc
Zn_0R_{40}	373pq	356j	40.3ab	38.9bc
Zn_0R_{80}	364q	242k	40.1ab	38.8bc
$Zn_{50}R_0$	414lm	401ghij	41.4ab	40.0bc
$Zn_{50}R_{10}$	512fg	487bcdef	45.3a	43.6abc
$Zn_{50}R_{20}$	501gh	473cdefg	44.4a	42.4bc
$Zn_{50}R_{40}$	451j	437efghi	42.8a	41.3bc
$Zn_{50}R_{80}$	404mn	391hij	42.1ab	50.5a
$Zn_{100}R_0$	524ef	502abcde	41.6ab	40.2bc
$Zn_{100}R_{10}$	538de	519abcd	32.0c	44.3abc
$Zn_{100}R_{20}$	549cd	530abc	47.0a	45.2abc
$Zn_{100}R_{40}$	471i	450defghi	43.7a	41.8bc
$Zn_{100}R_{80}$	425kl	413ghij	42.3ab	40.8bc
$Zn_{150}R_0$	566bc	545ab	41.9ab	40.3bc
$Zn_{150}R_{10}$	578ab	562a	47.8a	46.0abc
$Zn_{150}R_{20}$	585a	567a	48.2a	46.6ab
$Zn_{150}R_{40}$	485hi	463cdefgh	44.2a	42.0bc
$Zn_{150}R_{80}$	439jk	425fghij	42.5ab	41.0bc

See Table 2 foot notes. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

3.4 Total sugar and protein content in pods

Total sugar and total protein content in pods of green common bean were significantly increased by increasing the rate of Zn (Fig 4). Concerning gamma ray doses, 10 and 20 Gy has a much more significant effect comparable to the others. In this regard, 80 Gy resulted in higher reduction of total sugar and total protein than those recorded at 40, 80 Gy and the non-irradiated ones. Comparison between the two growing seasons reflected slight differences in total sugar and total protein. With respect to the effect of Zn rates, total sugar and total protein were gradually increased with increasing Zn rate up to 150 mg L^{-1}. The highest values were recorded at 150 mg Zn L^{-1}. Similarly, slight differences were observed between the growing seasons. The zinc concentration in the seed was found to be high at 27.78 mg kg^{-1}, whereas the protein concentration was the highest, which was 12.05%, as shown in treatment that received 60 kg ha^{-1} zinc sulphate. This phenomenon was given by the interaction of gamma irradiation doses and zinc application rates where the number of leaves, branches and green pods were improved by exposure to 10, 20 Gy and supplement with 150 mg Zn L^{-1} (Table 5). Although the exposure of seeds before planting to doses of 40 and 80 Gy caused a significant decrease, but the increase in Zn rate gave a significant increase in total sugar and total protein in dry pods of the green common bean. On other hand, the total sugar and protein were significantly increased in dry pods due to increases of zinc rates foliar applied and this finding was confirmed in both growing seasons whether that was in the main effect of spraying with zinc or when interacted with gamma irradiation.

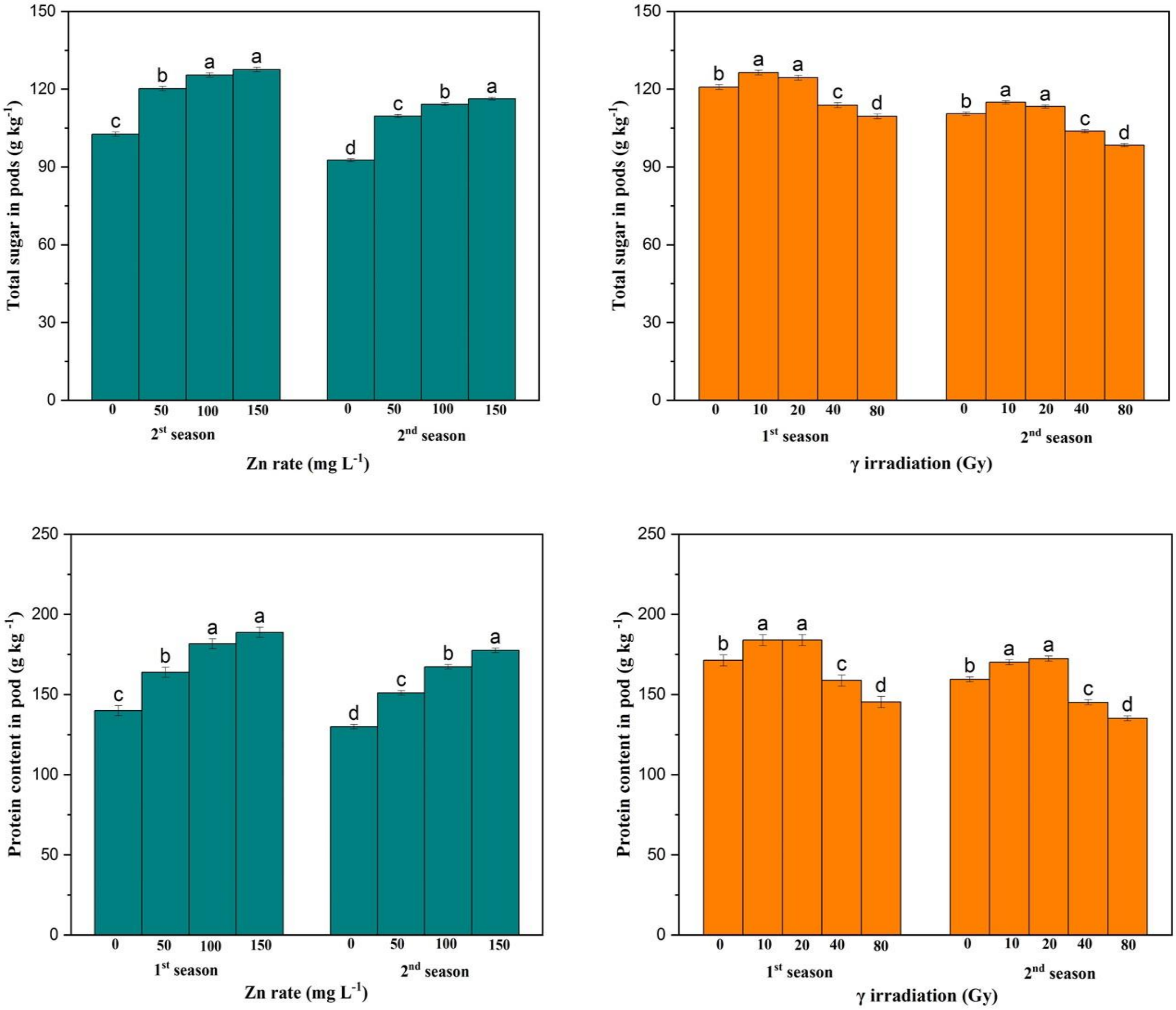

Fig. 4. Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on total sugar and protein content in pods. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

Table 5. Interaction effect of gamma irradiation and zinc spray on total sugar in dry pods and protein content in pods.

Treatments	Total sugar in pods (g kg^{-1})		Protein content in pod (g kg^{-1})	
	1st season	2nd season	1st season	2nd season
Zn_0R_0	103lm	94no	141g	131h
Zn_0R_{10}	110jk	98lm	139g	129h
Zn_0R_{20}	106kl	96mn	142g	132h
Zn_0R_{40}	99mn	90o	140g	130h
Zn_0R_{80}	95n	85p	138g	128h
$Zn_{50}R_0$	122dfeg	112efg	146fg	137gh
$Zn_{50}R_{10}$	126cde	115de	192abc	172d
$Zn_{50}R_{20}$	124def	113ef	180bcd	167de
$Zn_{50}R_{40}$	117ghi	107hi	157efg	143fg
$Zn_{50}R_{80}$	112ij	101kl	146fg	136gh
$Zn_{100}R_0$	128bcd	117cd	194abc	176cd
$Zn_{100}R_{10}$	134ab	122ab	199ab	183bc
$Zn_{100}R_{20}$	132ab	121ab	203a	191ab
$Zn_{100}R_{40}$	119fgh	109ghi	165def	150f
$Zn_{100}R_{80}$	115hij	103jk	147fg	138gh
$Zn_{150}R_0$	130abc	119bc	204a	194a
$Zn_{150}R_{10}$	136a	124a	206a	196a
$Zn_{150}R_{20}$	135a	123ab	210a	200a
$Zn_{150}R_{40}$	120efgh	110fgh	173cde	159e
$Zn_{150}R_{80}$	116ghi	105ij	151efg	138gh

See Table 2 foot notes. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

3.5- Fresh and dry biological yield

Gamma doses of 10 and 20 Gy resulted in higher significant yield than those detected with 40 and 80 Gy doses. Comparison held between the different gamma ray doses reflected that seeds exposed to 80 Gy resulted in the highest reduction of biological yield. It seems that this dose, to some extent, inhibited biological yield. Slight differences in biological yield was detected between the two growing seasons (Fig. 5 and Table 6). Concerning the effect of gamma irradiation, seeds irradiated with 40 Gy resulted in the highest value of fresh and dry weight of green common bean plants compared to the other tested doses in both seasons. The interaction between Zn_{150} and R_{20} resulted in significant enhancement in biological yield (fresh and dry).

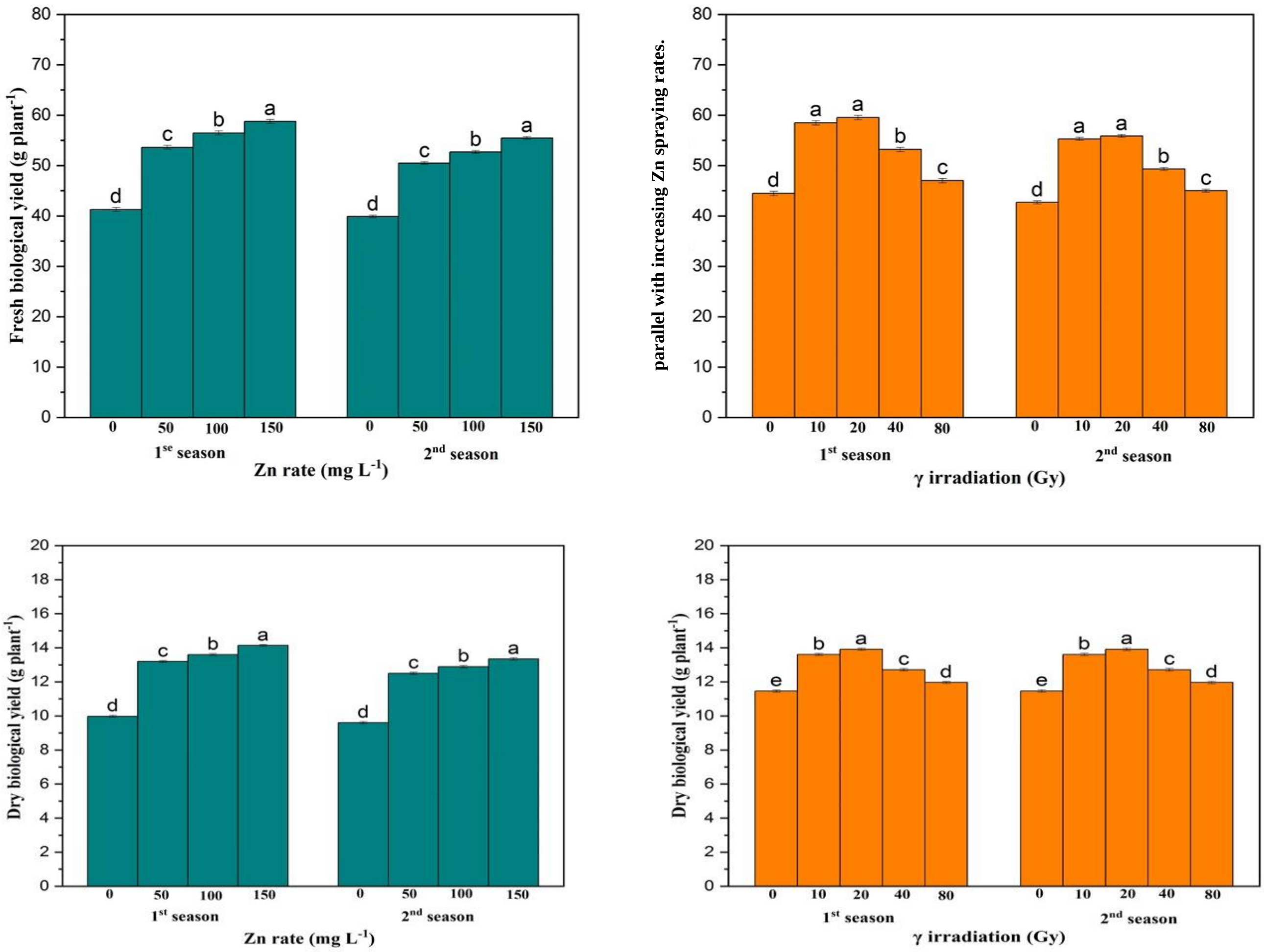

Fig. 5. Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on common bean fresh and dry biological yield. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

Table 6: Interaction effect of gamma irradiation and zinc spray on common bean fresh and dry biological yield

Treatments	Fresh biological yield (g plant^{-1})		Dry biological yield (g plant^{-1})	
	1st season	**2nd season**	**1st season**	**2nd season**
Zn_0R_0	41.4mno	40.2lm	10.0n	9.5m
Zn_0R_{10}	42.3lmn	40.7klm	10.3n	10.1i
Zn_0R_{20}	43.2klm	41.6jkl	10.9m	10.5kl
Zn_0R_{40}	40.4no	39.3mn	9.6o	9.1mn
Zn_0R_{80}	39.1o	37.8n	9.1p	8.9n
$Zn_{50}R_0$	44.2kl	42.4jk	11.6l	10.8jk
$Zn_{50}R_{10}$	61.3de	57.2d	14.3de	13.6d
$Zn_{50}R_{20}$	60.2ef	55.4e	14.1def	13.4de
$Zn_{50}R_{40}$	54.3g	51.4f	13.5gh	12.8fg
$Zn_{50}R_{80}$	48.0i	46.1hi	12.6j	11.9h
$Zn_{100}R_0$	45.1jk	43.2j	12.1k	11.1ij
$Zn_{100}R_{10}$	63.5cd	60.0c	14.4cd	13.8cd
$Zn_{100}R_{20}$	64.7bc	61.0c	14.8c	14.1bc
$Zn_{100}R_{40}$	59.5ef	52.5f	13.8gh	13.1ef
$Zn_{100}R_{80}$	49.5hi	46.8h	12.9i	12.4g
$Zn_{150}R_0$	47.1ij	45.0i	12.2jk	11.5i
$Zn_{150}R_{10}$	66.8b	63.3b	15.4b	14.4b
$Zn_{150}R_{20}$	70.1a	65.5a	15.9a	14.9a
$Zn_{150}R_{40}$	58.5f	54.3e	13.9ef	13.3de
$Zn_{150}R_{80}$	51.4h	49.3g	13.3hi	12.7fg

See Table 1 foot notes. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

3.6 Pod green yield, pod dry yield and zinc uptake

Pod yield (green or dry) was significantly increased by increasing the rate of Zn, but there were non-significant differences between 100 and 150 mg Zn L^{-1}. Similar enhancement effect on pod yield was detected when seeds prior to planting exposed to 10 and 20 Gy as compared to 40 and 80 Gy doses. On the other hand, exposure to 80 Gy resulted in the highest reduction in pod yield comparable to other doses and the non-irradiated ones. It seems that this dose, to some extent, inhibited pod yield. This trend was true in the two growing seasons (Fig. 6). With respect to the effect of Zn rates, pod yield was gradually increased with increasing Zn rate up to 150 mg L^{-1}. Values recorded at 150 mg Zn L^{-1} was the highest significant ones. Zinc uptake was significantly increased by increasing Zn rate. As detected with the abovementioned characteristics, the rate of 150 mg L^{-1} has the same role in achieving the highest values of Zn uptake. Similarly, Gamma radiation at 10 and 20 Gy recorded the optimum increases in Zn uptake as compared to 0, 40 and 80 Gy doses (Table 7). Raising gamma doses to 40 and 50 Gy has a contribution in depressing Zn uptake plants. Slight differences in Zn uptake was detected between the two growing seasons. The highest common bean pods yield, whether green or dry was given by the treatments that received the high level of foliar zinc (Zn_{150}) application interacted with 20 Gy (R_{20}) in both seasons. There were no significant differences found in the first season between the treatment that received 10 Gy (R_{10}) and the treatment that received 20 Gy (R_{20}) under the conditions of spraying with a high level of zinc (Zn_{150}), as these two treatments gave the highest yield of green or dry pods. Enhancement of common bean pods yield was continued with increasing zinc applied rates either individually or interacted with gamma ray only at 10 and 20 Gy doses, then tended to decrease with doses of 40 and 50 Gy. On other turn, exposure to 10 and 20 Gy doses had activated and enhanced the pod yield and zinc uptake parallel with increasing Zn spraying rates.

Table 7. Interaction effect of gamma irradiation and zinc spray on pod green yield, pod dry yield and zinc uptake by pods

Treatments	Pod green yield (Mg ha^{-1})		Pod dry yield (Mg ha^{-1})		Zn uptake by pods (kg ha^{-1})	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zn_0R_0	11.1lmn	9.5gh	1.4lmn	1.2gh	0.04no	0.04ij
Zn_0R_{10}	11.7klm	10.0fgh	1.5klm	1.3fgh	0.05mn	0.04ij
Zn_0R_{20}	12.2jkl	10.1fgh	1.5jkl	1.3fgh	0.05m	0.04ij
Zn_0R_{40}	10.4mn	9.3gh	1.3mn	1.2gh	0.04op	0.03ij
Zn_0R_{80}	9.9n	8.3h	1.3n	1.1h	0.04p	0.03j
$Zn_{50}R_0$	12.7ijkl	10.1fgh	1.6ijkl	1.3fgh	0.06l	0.05hi
$Zn_{50}R_{10}$	16.0abcde	13.5bcde	2.0abcde	1.7bcde	0.09d	0.07cde
$Zn_{50}R_{20}$	15.6bcdef	14.2abcd	2.0bcdef	1.8abcd	0.08de	0.08cde
$Zn_{50}R_{40}$	14.7efgh	13.5bcde	1.9efgh	1.7bcde	0.07hi	0.07defg
$Zn_{50}R_{80}$	13.4fghijk	12.4cdef	1.7fghijk	1.6cdef	0.06kl	0.06gh
$Zn_{100}R_0$	13.0hijk	11.7efg	1.6hijk	1.5efg	0.08ghi	0.07defg
$Zn_{100}R_{10}$	16.4abcd	14.0abcde	2.1abcd	1.8abcde	0.10c	0.08bc
$Zn_{100}R_{20}$	16.8abc	15.4ab	2.1abc	2.0ab	0.10bc	0.09ab
$Zn_{100}R_{40}$	15.0defg	14.1abcd	1.9defg	1.8abcd	0.08fgh	0.07cdef
$Zn_{100}R_{80}$	13.9fghij	12.8cde	1.8fghij	1.6cde	0.07jk	0.06fg
$Zn_{150}R_0$	13.3ghijk	12.1def	1.7ghijk	1.5def	0.08ef	0.07cde
$Zn_{150}R_{10}$	17.2ab	14.6abc	2.2ab	1.9abc	0.11ab	0.09ab
$Zn_{150}R_{20}$	17.6a	16.1a	2.2a	2.0a	0.11a	0.10a
$Zn_{150}R_{40}$	15.2cdef	14.5abc	1.9cdef	1.8abc	0.08efg	0.08cd
$Zn_{150}R_{80}$	14.2fghi	13.1bcde	1.8fghi	1.7bcde	0.07ij	0.06efg

See Table 2 foot notes. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

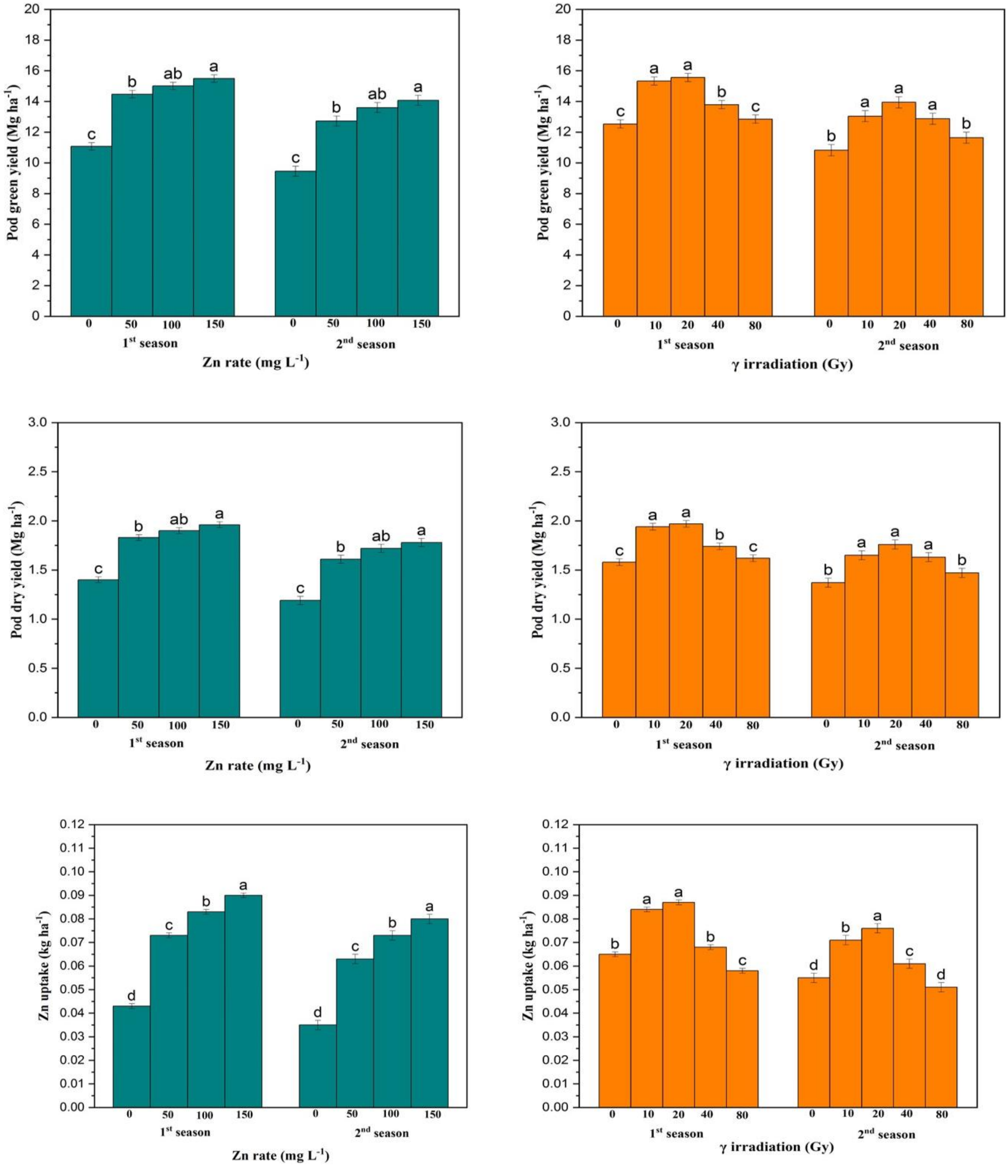

Fig. 6 . Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on pod green yield, pod dry yield and zinc uptake by pods. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

3.7 N, P and K uptake by pods Macro nutrients uptake (NPK) were significantly affected by gamma irradiation doses and Zn application rates (Fig. 7 and Table 8). NPK uptake exposed to either 10 or 20 Gy, although they nearly closed to each other, tended to increase over those exposed to 40 and 80 Gy dose. It is worthy that 80 Gy resulted in reduction of the uptake comparable to other doses or the non-irradiated ones. Slight differences in nutrient uptake were detected between the two seasons. With respect to the effect of Zn rates, the NPK uptake was gradually increased with increasing Zn rate up to 150 mg L^{-1}. Values recorded at 100 and 150 mg Zn L^{-1} were nearly closed to each other.

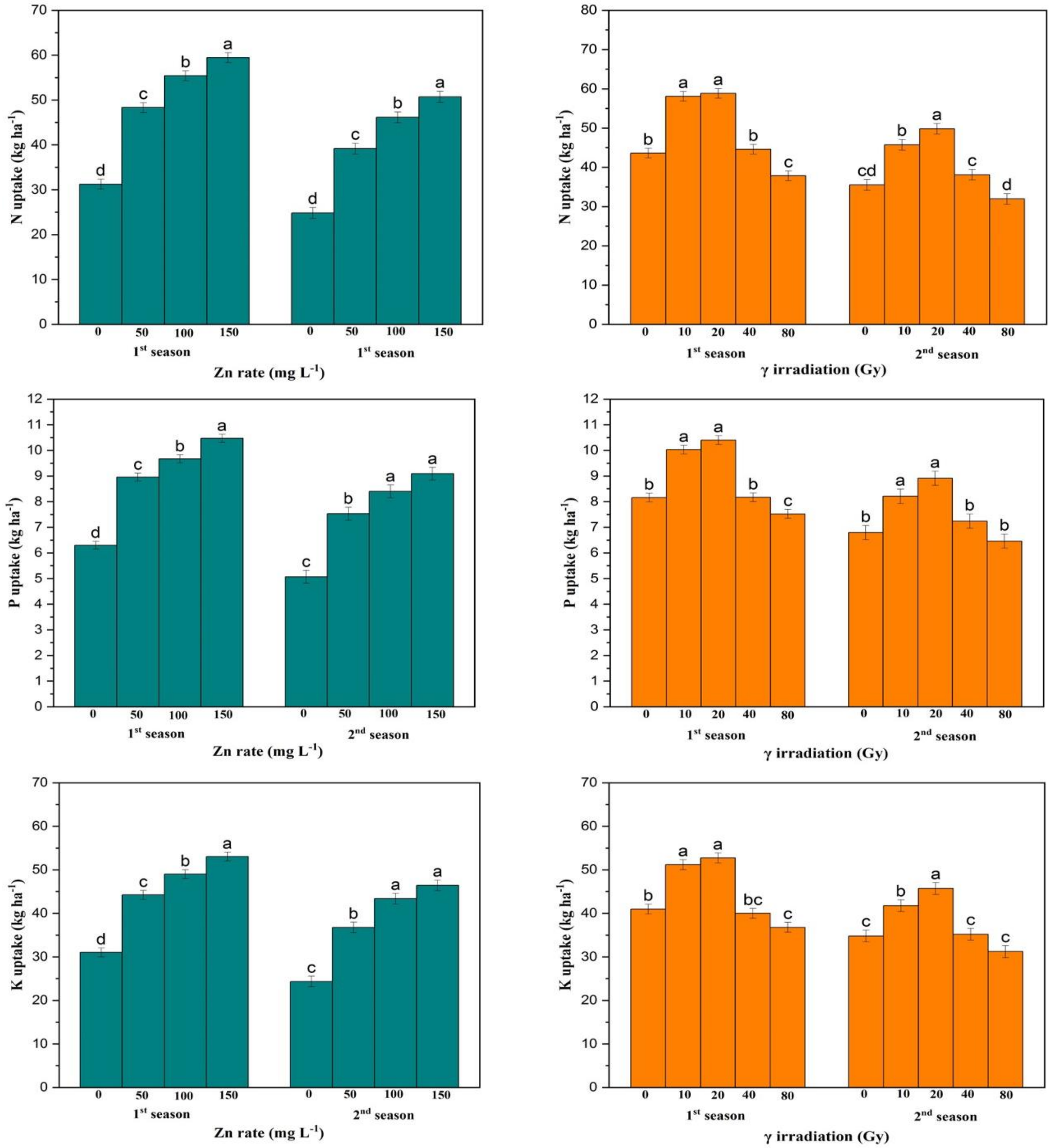

Fig. 7. Main effect of gamma irradiation (Gy) and zinc spray (mg L^{-1}) on N, P and K uptake by pods. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

4. Discussion

Results obtained in the present work indicated an enhancement of growth traits such as plant height and pod length due to exposure to low irradiation dose rather than the highest doses. It seems that lower irradiation dose act as activator for plant metabolites that positively affect the plant cell elongation which impacted the plant growth. Interaction between irradiation and Zn foliar application reflected the positive effect of Zn on growth parameters which tended gradually to increase with increasing Zn application rates. Similar trend of both irradiation doses and Zn rates was observed with no. of leaves, branches and green pods per plant. Most of the green vegetative growth parameters of common bean were improved by foliar application rates of Zn. We can conclude that green growth traits of common bean were positively/negatively responded to irradiation doses and

Zn application rates. In agreement with us, **Mittler, (2002); Jan *et al.* (2012)** attributed such responses to reduction in physiological and biochemical characteristics of irradiated plants that exposed to high dose which produced free radicals responsible to such adverse effects on plant. In the same way, **Wi *et al.* (2007)** explored that high doses of irradiation have a negative effect on signalling pathway of growth regulatory factors such as cytokinins and attributed this to cell oxidation. On the other hand, many researchers recorded positive effect of moderate doses of gamma radiation on leaves number of snap bean and tomato **(Soliman and Abd-El-Hamid, 2003; Amer, 2004; Hamideldin, 2010)**. In harmony with us, application of 10 kg Zn ha^{-1} significantly enhanced plant height, plant dry weight (g), number of leaves per plant and number of branches per plant of rapeseed **(Kumar *et al.* 2018)**, and tomato **(Johura *et al.*, 2021; zaghloul *et al.*, 2021)**.

Table 8. Interaction effect of gamma irradiation and zinc spray on N, P and K uptake by pods

Treatments	N uptake by pods (kg ha^{-1})		P uptake by pods (kg ha^{-1})		K uptake by pods (kg ha^{-1})	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
Zn_0R_0	31.3lm	25.2i	6.7ij	5.5hijk	32.7jk	27.1ijk
Zn_0R_{10}	32.9klm	26.1hi	6.7ij	5.4hijk	32.6jk	25.4jk
Zn_0R_{20}	35.1jklm	26.9hi	6.9i	5.3ijk	33.9jk	25.4jk
Zn_0R_{40}	29.4m	24.4i	5.8jk	4.9jk	28.7k	23.2jk
Zn_0R_{80}	27.6m	21.6i	5.5k	4.3k	27.3k	20.7k
$Zn_{50}R_0$	37.6ijkl	28.0ghi	8.1gh	6.1ghij	38.9hij	29.9hij
$Zn_{50}R_{10}$	61.8cd	47.1cde	10.3de	8.4cdef	51.2cde	41.3cde
$Zn_{50}R_{20}$	56.5de	47.9cd	10.3de	9.0bcd	51.8cd	46.1bcd
$Zn_{50}R_{40}$	46.3fgh	38.9ef	8.5fgh	7.5defg	41.6ghi	34.9fghi
$Zn_{50}R_{80}$	39.4hijk	34.0fgh	7.7hi	6.8fghi	37.8ij	31.6ghij
$Zn_{100}R_0$	51.0ef	28.0def	8.7fgh	7.5defg	44.2fghi	39.7cdef
$Zn_{100}R_{10}$	66.0bc	47.1bc	11.0cd	9.1bcd	57.8bc	48.2bc
$Zn_{100}R_{20}$	69.1abc	47.9ab	11.5bc	10.2ab	59.9ab	53.9ab
$Zn_{100}R_{40}$	49.9efg	38.9def	9.0fg	8.0def	43.7ghi	40.2cdef
$Zn_{100}R_{80}$	41.0hij	34.0fg	8.2gh	7.2efgh	39.5hij	34.9fghi
$Zn_{150}R_0$	54.7de	47.4cde	9.2fg	8.1def	48.1def	42.5cde
$Zn_{150}R_{10}$	71.6ab	58.0ab	12.2ab	10.0abc	63.1ab	52.2ab
$Zn_{150}R_{20}$	74.9a	64.9a	13.0a	11.1a	65.3a	57.5a
$Zn_{150}R_{40}$	52.8ef	46.6cde	9.4f	8.6bcde	46.1defg	42.5cde
$Zn_{150}R_{80}$	43.3ghi	36.6f	8.7fgh	7.7defg	42.6ghi	37.7defg

See Table 2 foot notes. Different lowercase letters indicate statistical differences among treatments at $p < 0.05$.

Leave area and total chlorophyll were to some extent, enhanced by lower irradiation doses comparable to the highest ones. This results are in harmony with those reported by **Mounir *et al.* (2022)**. With regard to gamma irradiation, chlorophyll was slightly influenced by the tested gamma irradiation doses. However, the highest chlorophyll content was achieved by 60 Gy dose. This holds true in both season. On the other hand, **Shala (2019)** recorded opposite trends. Similar effects of Zn rates were observed on leave area and total chlorophyll content (**Capo e*t al.*, 2024).** Total sugar and protein content in dry pods were increased by the combinations of high Zn concentration and irradiation doses. In this respect, **Ognyanov *et al.* (2022)** detected that large levels of total sugar in dried rose hip were produced by gamma rays at doses of 10 and 25 kGy. Another research showed high protein content due to exposure of sesame seeds to 1.5 and 2 kGy of gamma radiation **(Hassan *et al.*, 2018)**. Similar findings were reported by **Sadeghi *et al.* (2021)** who found that amount of zinc consumed enhanced the amount of total carbohydrates and seed protein.

Fresh and dry biological yield of common bean were expanded by the interaction between high Zn concentration and irradiation doses. This result is in agreement with **Supanjani *et al.* (2024)** who concluded that biological yield (fresh and dry) followed the same trend like vegetative growth traits under given conditions of Zn and gamma irradiation treatments. Biological yield was significantly increased by increasing the rate of Zn. In this context, the application of zinc boosted the final biomass and grain output of maize, despite the lack of particular data regarding plant development **(Drissi *et al.*, 2015; Imran *et al.*, 2016)**. Pod green and dry yield followed the same trend of fresh and dry biological yield that enhanced by the high Zn rate and low gamma doses. These results were consistent with those of **Mounir *et al.* (2015)**, who showed that pre-sowing seeds exposed to 20 Gy of low gamma irradiation increased snap bean pod yield (green and dry) considerably. A similar radiation response was also observed for Zn uptake at 0.005 kGy **(Singh and Datta, 2010)**. The applied Zn has many benefits under low doses of irradiation. Zinc content and its uptake were significantly higher under all fertilizer treatments particularly Zn treated plot as compared to control **(DAS *et al.*, 2021)**. According to **Behera *et al.***

(2008), ongoing crop cultivation with or without NPK fertilizer application resulted in decreased zinc absorption in plots without applied zinc as compared to treatments with zinc fertilization. **Rathod *et al.* (2012)** reported that applying zinc to wheat resulted in an increase in zinc uptake. One efficient way to increase both the production and quality of sugar beets at the same time is to apply fertilizer containing zinc at a rate of 30 kg ha^{-1} **(Zhao *et al.*, 2023)**. Applying zinc stunted development, possibly because it upset the equilibrium between the plant's consumption of zinc and that of the soil **(Sánchez-Rodríguez *et al.*, 2022)**. Gamma irradiation could be accepted as activated ones used for enhancing the physiological and metabolic activities of common been plants which reflected an improvement of yield and nutrient acquision **(Roshdy *et al.*, 2023)**.

Recently, more studies were dealt with the application of gamma irradiation technique on plant seeds and its effect on NPK uptake. **Farid *et al.* (2021)** concluded that gamma-ray irradiation of seeds at rate of 20 Gy significantly boosted N, P, and K uptake, which in turn greatly increased the dry yield. This may have occurred as a result of seed irradiation, which significantly increased root growth in seek of nutrients in soil **(Li *et al.*, 2016)**. **Hekal and Moussa (2023)** found that gamma radiation may enhance the yield by increasing K uptake. Similarly, slight differences were observed for both growing seasons. **Mosaad (2019) and Bashir *et al.* (2023)** found that increasing the rate of Zn in the spray solution was led to increase the uptake of N, P and K in plant. In the same way, N, P and K uptake by pods followed the same trend like pods dry yield under conditions of Zn and gamma irradiation treatments.

5- Conclusion

In this study, spraying green common bean plants with zinc and seed irradiation prior to cultivation plants were carried out in order to the response of green common beans to foliar zinc spraying and activated gamma-ray doses. The results demonstrated that irradiation of green bean seeds before planting with doses of 10 and 20 gray of gamma rays gave the highest plant length, leaf area, number of pods per plant, pod length, biological yield, pod yield, nitrogen uptake, protein content of seeds, total sugar and zinc uptake by pods. It was also concluded that when we increase the dose of zinc in the spray solution up to 150 mg L^{-1}, all the measurements were enhances germination percent, plant height, pod length, no. of leaves, no. of branches, no. of green pods, leave area, total chlorophyll, total sugar, protein content, yield, Zn, N, P and K uptake.

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