EFFECTS OF SEEDS IRRADIATION WITH GAMMA-RAY ON PLANT GROWTH AND YIELD ATTRIBUTING CHARACTERS OF SAFFLOWER

IVANOVA Raisa, SMEREA Svetlana

Abstract. The purpose of this study was to evaluate the impact of pre-sowing gamma irradiation with various doses of safflower seeds and time of seeds sowing on bio-morphological characters of plants. Based on ANOVA analysis there was showed that the time of seeds sowing statistically significantly influenced the height of safflower, number of developed and undeveloped inflorescences per plants more than the radiation. However, the contribution of radiation to the number of undeveloped inflorescences per plant was approximately seven times greater than the contribution of sowing time. The interaction between radiation and sowing time factors contributed to changes in number of secondary branches and developed inflorescences per plant. The correlations between the bio-morphological characters of plants growing under the same conditions demonstrated the strong direct proportional dependences of developed inflorescences on number of secondary branches per plant as well as the direct correlation between developed inflorescence and number of seeds per plant in all experimental variants. Thus, the safflower plants obtained from irradiated seeds which were sown in fall showed a more significant response to the abiotic factor (gamma radiation) by modifying the bio-morphological characters in comparison with the spring sown safflower.

Keywords: safflower, seed, gamma radiation, bio-morphological characters, yield.

Rezumat. Efectele iradierii seminţelor cu raze gamma asupra creşterii plantelor şi a caracterelor atribuite productivităţii şofrănelului. Scopul acestui studiu a fost de a evalua impactul iradierii gamma cu diferite doze a seminţelor de şofrănel înainte de semănat şi epocii de semănat asupra caracterelor bio-morfologice ale plantelor. În baza analizei ANOVA s-a constatat că, epoca de semănat a influenţat statistic semnificativ asupra înălţimii şofrănelului, numărului de inflorescenţe dezvoltate şi nedezvoltate per plantă mai mult decât radiaţia. Cu toate acestea, contribuţia radiaţiei la numărul de inflorescenţe nedezvoltate per plantă a fost aproximativ de şapte ori mai mare decât contribuţia epocii de semănat. Interacţiunea dintre factorii de iradiere şi epoca de semănat a contribuit la modificarea numărului de lăstari secundari şi a inflorescenţelor dezvoltate per plantă. Corelaţiile dintre caracterele bio-morfologice ale plantelor cultivate în aceleaşi condiţii au demonstrat dependenţa puternică direct proporţională a inflorescenţelor dezvoltate de numărul de lăstari secundari per plantă, precum şi corelaţia directă dintre numărul de inflorescenţe dezvoltate şi numărul de seminţe per plantă în toate variantele experimentale. Astfel, plantele de şofrănel obţinute din seminţe iradiate care au fost semănate în toamnă au demonstrat un răspuns mai semnificativ la factorul abiotic (radiaţia gamma) prin modificarea caracterelor bio-morfologice în comparaţie cu şofrănelul semănat primăvara.

Cuvinte cheie: şofrănel, seminţe, gamma radiaţie, caractere bio-morfologice, productivitate.

INTRODUCTION

Safflower (*Carthamus tinctorius*) plants are valuable agronomic species for different practical purposes: seeds – bird and animal feed; seeds oil – food, containing alphatocopherol; bee plants – flower for honey production; red and yellow pigments of petals - food colorants; ornamental plants; post-harvesting silage for livestock feed; source of biologically active substances - folk medicine. The pre-sowing treatments of seed with physical methods are used in order to stimulate the physiological processes in plant metabolism: germination energy, photosynthetic and enzymes activity, redox processes, secondary metabolites accumulation (MOGHADDAM et al, 2011; AKSYONOV, 2013). The gamma rays are the most efficient ionizing radiation and often applied on plants for developing varieties which are agriculturally and economically important as well as comprise high productivity and efficiency potential (KIM et al., 2004; HEGAZI & HAMIDELDIN, 2010; JAN et al, 2012). It was reported (PATIL et al., 2001; KAYA et al., 2009) that the biological and genetic characters of safflower modified by gamma irradiation of seeds resulted in increasing of plants yield. Expression of various characters is often changed as results of changing breeding materials and environment. Therefore, the information about inter relationships between plant bio-morphological characters and yield is important for determination the component character on which selection can be based for improvement in safflower yield (ARSLAN, 2007). The present work was intended to investigate the impact of pre-sowing gamma irradiation of safflower seeds with various doses and effects of seed sowing time on bio-morphological characters of plants in term of growth and seed yield.

MATERIAL AND METHODS

Plant materials were obtained from field experiments which were carried out at the research field station of Institute of Genetics and Plant Protection in Chisinau area of Republic of Moldova (lat. 47°01', long. 28°75', alt. 85 m above sea level), in the season of 2016-2017. Safflower seeds were treated with three doses of γ-radiation (50, 100, 150Gy) using gamma RXM-V-20 system, the radiation source - ^{60}Co. Irradiated seeds were sown in experimental field in fall on November 07, 2016 and in spring on April 05, 2017. The row spacing of plantation was 50cm and intra-row spacing - 15cm. Each row consisted of 50 seeds, in triplicate. Plants were grown in poor, dry soil, without irrigation. The plants grown from intact (untreated with gamma radiation) seeds served as control.

T**he bio-morphological characters of safflower plants** were studied according AHMADZADEH (2013), namely plant height (cm), number of secondary branches, number of inflorescences per plant, number of seeds per plant, number of seeds per capitulum, 1000-seed weight (g), seed yield (g).

The software package Statgraphics Plus 2.1 was used for statistical analysis. The ANOVA test was applied for variance analysis of bio-morphological characters, and Student test in assessment of statistically significant differences between treatments (RAUDONIUS, 2017).

RESULTS AND DISCUSSIONS

The morphological characters of safflower plants grown in experimental field showed that the plants height varied from 41 to 111cm (Table 1). The number of secondary branches per plant was minimum 2 and maximum 18, having up to 31 developed inflorescences and 38 undeveloped inflorescences. However, the average of developed inflorescences per plant was 2-3 times more than undeveloped inflorescences. It is important to note that the values of bio-morphological characters of safflower plants were modified depending on weather conditions of vegetation season. Our experiences of spring sown safflower in 2015 showed that the height of plant varied from 33 to 78cm (IVANOVA, 2016); and in 2016 it was 61-110cm (IVANOVA et al., 2017). In different seasons the average of safflower height was 59.25cm (2015) and 86.66cm (2016). Data obtained in 2017 (Table 1) statistically confirmed the growth potential of safflower in our experimental field and pedoclimatical conditions of the Republic of Moldova. The number of secondary branches, developed and undeveloped inflorescences per plant also differed from year to year. According to bio-morphological characters of safflower the best season was in 2016, the worst - in 2015.

Table 1. Bio-morphological characters of safflower sown in different time.

Time of sowing	Index	Characters of plants from seeds irradiated by different dose			
		Control	50Gy	100Gy	150Gy
Height					
Fall	average ±SE	76.51±2.56	77.38±1.83	75.39±2.39	71.65±2.29
	min ÷ max	47.0÷111.0	55.0÷98.0	56.0÷92.0	58.0÷100.0
	coefficient of variation,%	19.19	13.81	13.47	13.16
Spring	average ±SE	66.86±1.47	66.60±1.26	67.92±2.04	67.60±1.70
	min ÷ max	41.0÷95.0	46.0÷88.0	46.0÷81.0	54.0÷88.0
	coefficient of variation,%	16.47	14.44	14.69	12.57
Secondary branch					
Fall	average ±SE	6.48±0.37	7.24±0.53	8.67±0.92*	5.82±0.50
	min ÷ max	3÷12	3÷14	4÷16	2÷9
	coefficient of variation,%	32.96	43.05	45.12	35.52
Spring	average ±SE	7.38±0.42	7.31±0.29	7.21±0.41	8.32±0.49
	min ÷ max	2÷18	2÷14	3÷11	5÷14
	coefficient of variation,%	42.38	30.23	27.74	29.59
Developed inflorescence					
Fall	average ±SE	13.18±1.27	17.94±1.94*	20.33±2.99*	11.59±1.57
	min ÷ max	2÷31	5÷48	8÷52	2÷29
	coefficient of variation,%	55.44	63.30	62.55	55.93
Spring	average ±SE	12.55±0.97	11.93±0.85	12.38±1.68	14.44±1.24
	min ÷ max	2÷29	0÷31	0÷30	5÷33
	coefficient of variation,%	58.08	54.13	66.33	43.02
Undeveloped inflorescence					
Fall	average ±SE	4.64±0.67	6.29±0.70	11.56±1.77***	9.41±2.07**
	min ÷ max	0÷19	0÷16	0÷31	0÷30
	coefficient of variation,%	82.45	65.28	65.11	90.63
Spring	average ±SE	7.84±0.91	7.95±0.56	10.58±1.36	12.08±1.58
	min ÷ max	1÷38	2÷24	3÷34	2÷29
	coefficient of variation,%	87.26	53.30	63.04	65.35

Note: *; **; ***- denotes the statistically significant difference in comparison with control at $P \leq 0.05$; $P \leq 0.01$; $P \leq 0.001$, respectively

The safflower seeds can be sown in the fall as well as in the spring gratitude to their tolerance to low temperatures. The fall sowing safflower resulted in earlier flowering and maturity and increased yield compared to spring sown plants (PETRIE et al., 2010). The analysis of bio-morphological characters of safflower from two variants of sowing indicated that the height of safflower plants from fall sowing seeds was 9-10cm higher than the spring sowing plants (Table 1). Similar results were reported by ESENDAL et al. (2008); in fall sown safflower the value of plant height was the tallest (207.5cm), and the lower height was 55.2cm for spring sown plant.

In addition the fall sowed plants had undeveloped inflorescences less by 1.67 times comparing to the spring-sown plant. The applied doses of radiation did not have significant influence on height of safflower plants both fall and spring sowing. However, the dose of 50Gy had the statistically significant impact at $P \leq 0.05$ on the number of developed inflorescences per plant of fall sown safflower. Increasing the dose up to 100Gy for seeds irradiation led to statistically rising of secondary branches number and developed inflorescences per plants. It is important to mention, that the number of undeveloped inflorescences also increased significantly. The plants of fall sowing from seeds treated by 150Gy doses had the worst bio-morphological characters in comparison with other experimental variants (Table 1). Concerning the studied characters of plants obtained from irradiated and control safflower seeds sown in spring there were no statistically significant differences between the values. The safflower plants obtained from irradiated seeds which have been sown in fall in experimental field have shown a significant response to an abiotic factor (gamma radiation) by changing their bio-morphological characters in comparison to spring sown safflower.

The impact evaluation of factors such as radiation and seed sowing time (fall or spring) on bio-morphological characters of safflower plants was carried out by ANOVA analysis (Table 2). The time of seeds sowing statistically significantly influenced the height, number of developed and undeveloped inflorescences per safflower plants more than the radiation. However, the contribution of radiation to the number of undeveloped inflorescences per plant was approximately 7 times greater than the contribution of sowing time. The interaction between radiation and sowing time factors contributed to changes in number of secondary branches and developed inflorescences per plant (Table 2).

Table 2. Impact of radiation and seed sowing time on bio-morphological characters of safflower.

Source	Sum of squares	Df	Mean square	F-ratio	P-value	Source contribution,%
Height						
Radiation (R)	166.45	3	55.48	0.48	0.6976	ns
Time of sowing (T)	3508.98	1	3508.98	30.26***	0.0000	10.01
Interactions R-T	345.59	3	115.20	0.99	0.3965	ns
Total	35051.30	264				
Secondary branch						
Radiation (R)	23.24	3	9.75	1.36	0.2569	ns
Time of sowing (T)	13.80	1	13.80	1.92	0.1672	ns
Interactions R-T	86.80	3	28.93	4.02**	0.0080	4.41
Total	1967.04	264				
Developed inflorescence						
Radiation (R)	441.54	3	147.18	2.20	0.0881	ns
Time of sowing (T)	474.26	1	474.26	7.10**	0.0082	2.50
Interactions R-T	909.61	3	303.20	4.54**	0.0040	4.80
Total	18959.90	264				
Undeveloped inflorescence						
Radiation (R)	1015.95	3	338.65	9.39***	0.0000	9.62
Time of sowing (T)	147.64	1	147.64	4.09*	0.0441	1.39
Interactions R-T	127.37	3	42.46	1.18	0.3188	ns
Total	10560.00	264				

Note: *; **; ***- denotes the statistically significant difference at P≤0.05; P≤0.01; P≤0.001, respectively

The correlations between the bio-morphological characters of plants grown in same conditions were determined by Pearson coefficients (Table 3). The strong direct proportional dependences of developed inflorescences on number of secondary branches per plant were determined in all variants of fall sown safflower and in control plant of spring sowing. Similar correlation between the number of secondary branches and developed inflorescences of Turkish safflower cultivars was described by BEYYAVAS et al. (2011).The irradiation of spring sown seeds provoked the disturbance of this regularity.

Table 3. Pearson correlation coefficient between number of secondary branches and developed inflorescence.

Sowing time	Control	50Gy	100Gy	150Gy
Fall	0.7783	0.8763	0.8054	0.7680
Spring	0.8398	0.6419	0.5354	0.5817

The number of seeds harvested per each safflower plant varied in large limits from one seed to 1719 seeds (Table 4). Because of that the impact evaluation of growing conditions and doses of radiation was carried out by averages of yield attributed characters. The safflower cultivated from untreated seeds (control) in fall sown field had 1.35 times higher number of seeds per plant in comparison with spring sown. The maximum amount of seeds was determined in variant 50Gy –fall-sown and was equal to 570.27. This character was significant (P≤0.05) higher, by 43.0%, than similar character of control plant.

The weight of seeds per plant also modified in the wide range from 0.01 to 53.60 g (Table 4). The weight of seeds from control field of fall-sown plant was 11.89g and spring-sown - 7.63g. Under the influence of radiation, the values of seeds weight were fluctuated towards rising or diminishing, but no significant changes were observed in all experimental variants.

The most important character of plant productivity is the weight of 1000 seeds (Table 4). The minimum and maximum values of this character varied from 10.70 to 53.30g and depended on sowing time and doses of gamma radiation. For comparison the 1000-seed weight in season of 2015 was 29.35g and in 2016 – 37.80g (IVANOVA, 2016; IVANOVA et al., 2017). The large dispersion of values of yield attributed characters of safflower plants was also reported by other scientists (KIZIL et al., 2008; BEYYAVAS et al., 2011; AHMADZADEH, 2013; SHINWARI et al., 2014; KHAKI-MOGHADAM & ROKHZADI, 2015). In our experiment the pre-sowing irradiation of seeds by 150Gy caused significant increase in 1000-seed weight, by 19% in the fall-sowing field ($P \leq 0.01$). One safflower capitula of control plants contained on average 21.62-30.26 seeds (Table 4). The significant impact of irradiation was established only in spring sowing field of seeds treated by 100Gy ($P \leq 0.1$). Safflower cultivated in semi-arid conditions of Turkey had 30.6-40.1 seeds per capitulum (KIZIL et al., 2008), but Iranian cultivars characterized by 8.4-13.6 seeds per capitulum (KHAKI-MOGHADAM & ROKHZADI, 2015). PATIL et al. (2001) discovered that this yield component (number of seeds per capitulum) due to gamma irradiation showed high variability in generation F_2M_2. Number of seed per capitulum in F_2 was 56.52; in M_2 - 36.26 and in F_2M_2- 77.00 (PATIL et al., 2001).

Table 4. Seed yield of safflower grown from seeds irradiated by different gamma dose.

Time of sowing	Index	Yield attributing characters of safflower plant from irradiated seeds			
		Control	**50Gy**	**100Gy**	**150Gy**
Number of seeds per plant					
Fall	average±SE	398.73±43.89	570.27±68.21*	535.18±111.21	265.12±35.62
	min ÷ max	35÷1102	103÷1719	137÷1625	75÷602
Spring	average±SE	295.41±29.05	296.57±25.47	374.61±60.63	344.68±40.58
	min ÷ max	6÷740	32÷721	1÷1051	45÷760
Weight of seeds per plant					
Fall	average ±SE	11.89±1.33	15.44±1.87	17.23±3.50	9.30±1.63
	min ÷ max	0.61÷33.85	2.49÷53.60	3.37÷53.51	2.85÷30.84
Spring	average ±SE	7.65±0.80	7.35±0.70	9.94±1.68	8.82±1.04
	min ÷ max	0.10÷20.36	0.71÷22.58	0.05÷32.80	0.78÷19.86
Weight of 1000 seeds					
Fall	average ±SE	29.63±0.91	28.39±1.02	33.65±1.94	35.39±2.62**
	min ÷ max	17.4÷38.6	14.1÷38.6	17.2÷47.8	17.0÷51.8
Spring	average ±SE	25.47±0.97	24.77±0.86	27.77±1.42	25.93±1.22
	min ÷ max	10.7÷53.3	10.9÷37.10	15.7÷50.00	13.4÷40.60
Number of seeds per capitulum					
Fall	average ±SE	30.26±1.28	32.15±2.42	25.01±3.20	23.95±1.89
	min ÷ max	2÷42	12÷83	11÷63	12÷46
Spring	average ±SE	21.62±1.16	22.83±0.99	26.08±2.10*	22.10±1.83
	min ÷ max	3÷43	8÷37	1÷49	4÷45

Note: *; ** - significant differences at $P \leq 0.1$; $P \leq 0.05$, respectively.

According to ARSLAN (2007) the yield of safflower seeds is determined by the number of developed inflorescences and number of seeds per capitulum since these characters had direct significant positive effects on seed yield. The results obtained by us showed that between the number of developed inflorescences per plant and the number of seeds per plant had a strong linear correlation ($r > 0.7$) which was established in all experimental variants (50, 100, 150Gy) and in control (Table 5). The exception was the variant 100Gy-fall sown plant, where the coefficient of linear correlation was equal to 0.6934. Thus, the correlation between the number of secondary branches and developed inflorescences as well as between developed inflorescences and number of seeds per safflower plant was determined. The results reported by BAHMANKAR et al. (2014) suggested that 1000-seed weight; developed inflorescences per plants have direct positive effect on seed yield. The researchers (BAHMANKAR et al., 2014) have concluded that the number of developed inflorescence per plant; 1000-seed weight and plant height are putative morphological markers which can be considered as the desirable tools for screening elite safflower genotype under the field conditions.

Table 5. Correlation coefficient of between developed inflorescence and number of seeds per plant.

Sowing time	Control	50Gy	100Gy	150Gy
Fall	0.9199	0.8763	0.6934	0.9433
Spring	0.9252	0.8781	0.9440	0.7596

Quantitative evaluation of bio-morphological characters of safflower plants obtained from gamma irradiated seeds was done in comparison to the control (Table 6). The analysis of variance for these indices by ANOVA test revealed specificity influences of cultivation conditions. The impact of gamma irradiation was not significant in the indices variation in field conditions of spring sowing safflower. At the same time, there was significant contribution of radiation to the variation of all characters analyzed at 90, 95 and 99% confidence intervals in fall sown plants (Table 6).

Table 6. Analysis of variance for bio-morphological characters (ANOVA test).

Source	Df	Characters	Sum of squares	Mean of squares	F-ratio	Contribution of source.%
Fall sowing						
Radiation	3	Number of seeds per capitulum	1094.3	364.765	2.94**	8.34
		Number of seeds per plant	1.27806E6	426019.0	3.77**	10.45
		Weight of seeds per plant	747.757	249.252	2.46*	7.06
		Weight of 1000 seeds	0.0007373	0.0002458	4.81***	12.96
Total	100	Number of seeds per capitulum	13122.7			
		Number of seeds per plant	1.22358E7			
		Weight of seeds per plant	10585.6			
		Weight of 1000 seeds	0.0056887			
Spring sowing						
Radiation	3	Number of seeds per capitulum	338.457	112.819	1.54	ns
		Number of seeds per plant	144252.0	48084.1	1.01	ns
		Weight of seeds per plant	133.132	44.3773	1.25	ns
		Weight of 1000 seeds	0.00015106	0.000503	1.08	ns
Total	159	Number of seeds per capitulum	11786.1			
		Number of seeds per plant	7.58969E6			
		Weight of seeds per plant	5674.05			
		Weight of 1000 seeds	0.0074015			

Note: *; **; *** - significant differences at $P \leq 0.1$; $P \leq 0.05$; $P \leq 0.01$, respectively

CONCLUSIONS

The correlations between the bio-morphological characters of safflower growing under the same conditions demonstrated the strong direct proportional dependences of developed inflorescences on number of secondary branches per plant as well as the direct correlation between developed inflorescence and number of seeds per plant.

The safflower plants obtained from irradiated seeds which were sown in fall showed a more significant response to the abiotic factor (gamma radiation) by changing their bio-morphological characters in comparison with the spring sown safflower.

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Ivanova Raisa, **Smerea Svetlana**
Institute of Genetics, Physiology and Plant Protection, No. 20, Pădurii Str., Chişinău MD-2002, Republic of Moldova.
E-mails: ivanova_raisa@yahoo.com; smerea_svetlana@yahoo.com

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