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GENOTYPIC X ENVIRONMENT INTERACTION OF CASTORBEAN GROWN OVER MULTIPLE YEARS

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ABSTRACT

This research work was performed at Nuclear Institute for Agriculture and Biology (NIAB) Faisalabad Pakistan and castor mutants under study were obtained after treating three castor varieties viz. DS 30, C 176 and DC 15 with gamma rays ranging from 100-500 Grey during Kharif 2003. The selection was performed in M_2 generation and confirmation of characters in the subsequent generations. Vigorous selections remained in progress during each succeeding generation for desirable yield and yield components. Then afterward these elite selected mutant lines were evaluated from 2007 to 2010 in randomized complete block design (RCBD) in three repeats. Combined analysis of variance indicated that genotypes (A), environment (B) and interaction between A x B was highly significant. Overall mean performance of castor mutants showed significant differences with maximum seed yield (2776 kg ha^{-1}) estimated in mutant M 7-35-12-1 and minimum in standard check DS 30 (1825 kg ha^{-1}). M 7-35-12-1 produced 52.10% higher seed yield followed by L 57-32-784 (39.78%) and M 7-35-1-2 (35.34%). Regarding regression coefficient (b), mutant line L 36-24-124 was more near to unity followed by M 7-35-12-1. Standard check DS 30 not only produced poorest seed yield but had very less regression coefficient value (0.585) which indicated that variety is most suited to special type of environment. The maximum value of regression coefficient was estimated in mutant DC 1525421 (b=1.299) which showed that the line is most suited for rich environment. Standard deviations to regression (Sd^2) values were not higher and less than unity and ranged from 0.107 to 0.390. Mutant line M 7-35-12-1 had minimum value and standard check DS 30 with highest value. Moreover, mutant line M 7-35-12-1 had less maturity period (125 days) as compared to 200 days of DS30 and it can easily be harvested in one cutting operation before cultivation of wheat and can be best fitted in wheat-castor rotation. Development of this early mutant has created the chances of adaptation of economically potential castor as major a crop that will contribute in meeting the increasing demands of castor oil.

Key words: Combined analysis of variance**,** *Ricinus communis* L., yield, environmental interaction

INTRODUCTION Running title: CASTORBEAN RESPONSE TO MULTIPLE ENVIRONMENTS

Castorbean (*Ricinus communis* L.) is an industrial oil seed crop containing about 57% oil. Castor oil is utilized in many industries like petrochemical, pharmaceuticals, cosmetics, textile, chemicals, soap, leather, paints, varnishes, ink, nylon, plastic and detergents. The oil of castorbean is also used as a medicine for the treatment of obstetrics, dermatology as purgative, laxative and as a smothering medicine in eye for removal of foreign bodies. In recent years, its conversion as bio-fuel has magnified its significance. Moreover, its oil does not freeze even at high altitudes and it is the best lubricant for jet engine and aeroplanes flying at high altitude. The shell of castorbean is used as an organic termite control in soil and its seed cake as manure (Moshkin, 1986; Maiti et *al.,* 1988).

Castorbean crop is grown on 8216 ha in Pakistan with an annual production of 4023 tones having an average seed yield of 490 kg ha^{-1} which is very low (Anonymous, 2008-9) as compared to the main castor growing countries of the world like India , China and Brazil which are producing 1266, 909 and 850 $kgha^{-1}$ seed yield (Anonymous, 2000), respectively. Pakistan is facing an acute shortage of edible oil and an amount of Rs.137 billion is being spent on its import. The country is producing only 30% of its requirement while 70% is being met through import. Castorbean and sesame are the only alternative crops to be used to compensate the foreign exchange expenditure by their export (Anonymous, 2005).

Although castor crop requires less water yet it is mainly produced on marginal lands and yields remain low. At present farmers are not inclined to plant this crop although it is a low input requiring crop and can be grown on marginal lands, because of unavailability of suitable and high yielding varieties to be fit in our cropping system. Much of the harvested crop is derived from semi wild cultivars having tall and indeterminate plant growth habit alongwith late and non synchronized maturity. To bridge the huge yield gap and to exploit the available cultivated area economically, it is entirely necessary to evolve new castor germplasm having high seed yield, early maturity with determinate

plant growth habit and disease resistance which are the main causes of low yield.

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In order to evolve such type of genotypes to be fit in the present cropping system, it is imperative to create genetic variability for selection of desirable traits for the development of improved variety. Induced mutation is an important supplementary approach for creation of positive genetic variability (Tepora, 1994). Further, more induced mutations have also potential to break the undesirable linkages between important economic traits. Mutation is capable of inducing permanent dormancy of axillary buds to stop iterative growth which is at the base of the perennial form of castorbean (Baldanzi *et al.,* 2003).

Although castor crop requires less water yet it is mainly produced on marginal lands and yields remain low. At present farmers are not inclined to plant this crop although it is a low input requiring crop and can be grown on marginal lands, because of unavailability of suitable and high yielding varieties to be fit in our cropping system. Much of the harvested crop is derived from semi wild cultivars having tall and indeterminate plant growth habit alongwith late and non synchronized maturity. To bridge the huge yield gap and to exploit the available cultivated area economically, it is entirely necessary to evolve new castor germplasm having high seed yield, early maturity with determinate plant growth habit and disease resistance which are the main causes of low yield. In order to evolve such type of genotypes to be fit in the present cropping system, it is imperative to create genetic variability for selection of desirable traits for the development of improved variety. Induced mutation is an important supplementary approach for creation of positive genetic variability (Tepora, 1994). Further, more induced mutations have also potential to break the undesirable linkages between important economic traits. Mutation is capable of inducing permanent dormancy of axillary buds to stop iterative growth which is at the base of the perennial form of castorbean (Baldanzi *et al.,* 2003).

Moreover many research workers have employed induced mutations for creation of genetic variability and have succeeded for the development of many useful traits in different oilseed crops. Bokhan (1988, 1989) observed that seed of VNIIMK165 Uluchshennyl treated with N-methyl-N-nitrosourea (MNU), ethyleneimine (EI), N-ethyl-N-nitrosourea, dimethyl suslfate and 1,4-bisdiazoacetylbutane produced different morphological mutations like height, length and ripening dates of the central and lateral inflorescences, number of lateral inflorescences and internodes, seed number and weight/plant, 1000-seed weight and length of a single internode. The greatest increase in variation was in yield components. Karve (1981) observed that following irradiation (10-50 kR) of Aruna seeds of castor variety, 11 M_2 plants with a slightly lower ricinoleic acid content, ranging from 81 to 84% were identified

By using both physical and chemical mutagens Tepora (1994) developed 4 mutants of castor possessing dwarfness, determinate, early and uniform maturity characteristics which may be used for dense planting to raise castor as a cash crop. In Korea a mutant variety of sesame with the name of Ahnsankkae was developed in 1984 by 20 Kr of X-ray irradiation, occupying 31% of total sesame area because of its high seed yield, uniform maturity and disease resistance. Suwonkkae was another variety developed through mutation and cross breeding techniques (Kang *et al*. 1994). Ashri (1994), Jamie *et. al.* (2002) and Uzun and Cagirgan (2006) developed determinate, short duration and high yielding mutants of sesame through induced mutations. Keeping in view the importance of induced mutations, work on castor improvement was initiated during 2003 with the goal to select mutants with special emphasis on plant architecture, suitable to our environment with stable genetic background having wider adaptability.

Seed yield is a multi-facet character and its ability is the result of favorable interaction of genotype with the environment. Specific response of a genotype may be observed in particular environment and its stable performance over different environments is a desirable characteristic, which depends on the magnitude of genotype x environment interaction (Ahmad *et al.,* 1996). A genotype is considered to have agronomic stability if it yields well with respect to the productive potential of the test environments (Romagosa *et al.,* 1999). The productivity of a population is the function of its adaptability, while the later is a compromise of fitness (stability) and flexibility. Stability of a genotype depends on the ability to retain certain morphological and physiological characters steadily allowing others to vary resulting in predictable G x E interactions for yield. A population that can adjust its genotypic and phenotypic state in response to environmental fluctuations in such a way to give high and stable yield is termed as "Well buffered". Eberhart and Russell (1966) model had been widely used to study stability parameters i.e. mean seed yield, regression coefficient and deviation from regression. The objective of the present study was to evaluate the performance of the newly developed castor mutants for seed yield and stability characteristics across five different environmental conditions.

MATERIALS AND METHODS

This research work was performed at Nuclear Institute for Agriculture and Biology (NIAB) Faisalabad Pakistan and castor mutants under study were obtained after treating three castor varieties viz. DS 30, C 176 and DC 15 with gamma rays ranging from 100-500 Grey during Kharif 2003 (Table 2). The selection was performed in M_2

generation and confirmation of characters in the subsequent generations. Vigorous selections remained in progress for desirable yield and yield components based on visual observations and genetic parameters studied earlier in different succeeding generations (Sarwar *et. al*. 2008, 2010). Then these elite selected mutant lines were evaluated from 2007 to 2010 under different environmental/weather conditions (Table 1), in randomized complete block design (RCBD) in three repeats. Four rows of each line were planted keeping inter and intra row spacing of 75 cm and 90 cm respectively. The data on single plant as well as plot basis were recorded for different morphological traits and Seed yield per plot was collected and data of seed yield was subjected to analysis of variance (Steel and Torrie 1980) and stability parameters were worked out following Eberhart and Russel Model (1966) and Singh and Chaudhry (1999).

RESULTS AND DISCUSSION

Performance of castor mutants in respect of seed yield (Table 3) showed that during 2007, significant differences in seed yield were observed. Castor mutant M 7-35-12-1 produced the highest seed yield (3088 kg ha^{-1}) followed by L 36-24-124 (2890 kg ha^{-1}) and M 7-35-1-2 (2664 kg ha^{-1}). However, statistically these mutant lines have non significant differences among each other but significant with the standard check DS 30 which produced 2032 kg ha^{-1} seed yield. Castor mutant M 7-35-12-1 produced maximum seed yield (3789 kg ha^{-1}) followed by L 5732784 (3687 kg ha^{-1}) and DC 15 M2271211 (3542 kg ha^{-1}) during 2008 (Table 3). The standard check DS 30 produced 1901 kg ha^{-1} seed yield. Statistically these results were also significant. During 2009 maximum seed yield was estimated in mutant line M 7-35-12-1 (1742 kg ha^{-1}) followed by L 3624124 (1675 kg ha^{-1}). These two mutants were statistically at par. The lowest seed yield was produced by check variety DS 30 (788 kg ha^{-1}). Overall the mutants in 2009 showed less yield potential as compared to other years/environments. Significant differences in seed yield among mutants were also observed during 2010 at both the locations (Table 2). At Faisalabad M 7-35-1-2 produced the highest seed yield (2755 kg ha^{-1}) followed by L 5732784 (2519 kg ha^{-1}) and M 7-35-12-1 (2437 kg ha^{-1}) as compared to 2087 kg ha^{-1} of Ds 30. castor mutant M 7-35-12-1 produced maximum seed yield (2824 kg ha^{-1}) followed by M 7-35-1-2 (2726 kg ha^{-1}) and L 5732784 (2706 kg ha^{-1}) as compared to 2317 kg ha^{-1} of DS 30 at Shorkot area.

Overall mean performance (Table 3) of castor mutants showed significant differences with maximum seed yield (2776 kg ha^{-1}) estimated in mutant M 7-35-12-1 and minimum in standard check DS 30 (1825 kg ha^{-1}). The 2nd position attained by mutant L 5732784 (2551 kg ha^{-1}) and 3rd by M 7-35-1-2 (2470 kg ha^{-1}). The mutant lines showed maximum yield potential during 2008 ranging from 2835 – 3789 kg ha^{-1} whereas minimum potential was achieved during 2009 ranging from 1200 – 1741 kg ha^{-1} which is all due to variation in the environment conditions that prevailed during the growth period of the castor crop (Table 1).

Results of combined analysis of variance indicated that genotypes (A), environment (B) and interaction between A x B was highly significant (Table-4). This may be due to different genetic make up of the breeding lines under study and further more because of the variation in the weather conditions (Table 1) that prevailed over the years when the crops was grown, especially in case of rainfall which was maximum during 2010 and continued for longer period during 2009. This significant interaction provided the base to go further for estimation of stability analysis. Pooled analysis of variance (Table-5) showed highly significant differences for environment, varieties, Env. + Var. x Env., Env. (Lin) and non linear components of G x E interaction (pooled deviations). This indicated that there were different genotype under study and the environments were also different. The significant genotype x environment interaction may be either a crossover G x E interaction or a non crossover. In crossover, significant change in ranks occurs from one environment to another (Matus *et al.,* 1997) and non crossover, the ranking of genotypes remains constant across environments and the interaction is significant due to change in the magnitude of response (Baker 1988, Blum 1983, Matus *et al.,* 1997). In the present study significant G x E interaction was of a crossover nature. Joshi *et al* (2002) studied a set of 112 crosses of castor under four artificially created environments to characterize stability for yield and its contributing components. Both linear and non-linear components of G x E interaction were found to be significant for all the traits except days to flowering and days to maturity revealing difficulty in prediction of performance of the characters studied in varied environments.

Kumari *et al.* (2003) studying 13 genotypes of castor (*R. communis*) in three environments found significant differences in genotype x environment interaction. They observed that early sowing was the most suitable environment for this crop. Koutroubas *et al.* (1999) also studied the adaptation and yielding ability of 19 modern *R. communis* genotypes at Thessaloniki, Loudias, and N. Greece and noted that *R. communis* is satisfactorily adapted in this area. Chand *et al.* (1982) observed that six new *Ricinus comminus* hybrids together with the earlier hybrids GAUCHI and GCH3 were evaluated at six sites in Gujrat during 1975-76 and 1976-77. Genotypes x environmental interactions were significant. VHB 82 and VHB 83 responded better than GAUCHI and GCH3 to favorable conditions, under which GUANCHI adopted better than GCH3. JHB 435 and VHB 1 responded well under unfavorable conditions. VHB 89 showed average stability with high mean yield while GCH3 showed average stability but responded poorly to environmental fluctuations.

Singh *et al.* (1998) studied 18 genotypes of sesame (*Sesamum indicum*) for stability parameters for seed yield and its components. Genotype-environment interaction was observed for all the traits. Linear as well as nonlinear components accounted for the interaction for all the characters except number of primary branches per plant. However, the former contribution to a greater extent.

Sojitra *et al.* (1998) studied stability parameters in groundnut and found the importance of non linear components. An unpredictable portion of G x E interaction was present. They further observed that genotypes with high shelling percentage were suitable for favorable environments. Bold podded cultivars were insensitive to changing environmental conditions, while the high shelling percentage genotype showed wide adaptation. Laurentin and Montilla (1999) evaluated stability parameters using eight genotypes of white grains sesame for yield in three years. None of the genotype showed stable performance over the years. Hassan and Abdalla (2004) evaluated sesame genotypes for four consecutives years. Both individual and combined analysis of variance showed significant differences among the genotypes for different economic traits under study. Genotypes x year interaction were also significant. Velu and Shunmugavalli (2005) studied 40 sesame genotypes for three seasons. Stability parameter indicated that five genotypes were stable across the environments. According to the stability index, the summer season was identified as the best environment for growing the present set of genotypes. Shim *et al.* (2003) testing seven varieties of sesame in a set of fifteen environments and observed significant differences in G x E interaction. It was concluded that specific genotypes for specific environment are needed in order to maximize grain yield in sesame. Genetic divergence between castor bean (*Ricinus communis* L.) cultivars was evaluated by Fortes *et al*. (2008) from adaptive traits, yield components and cultivar productivity using cluster analysis and principal components analysis. Tree groups were formed, and the one which comprised the cultivar more divergent was not recommended for hybridization due to its low performance. Promising combinations are those ones which had more dissimilarity and the best average performance. Studying six sesame mutants at four environments Sarwar *et. al.* (2010) observed significant and cross over type of interaction between environment x genotypes.

In this study almost all the mutant lines of castor produced significantly higher seed yield than check variety DS 30 (Table-6) on overall mean performance basis. However, first four i.e. M 7-35-12-1, M 7-35-1-2, L 57-32-784 and L 36-24-124 produced higher seed yield than grand mean (2328 kg ha^{-1}). Overall 16.38 to 52.10% higher seed yield was estimated in castor mutants and M 7-35-12-1 produced 52.10% higher seed yield followed by L 57-32-784 (39.78%) and M 7-35-1-2 (35.34%). Regarding regression coefficient (b) mutant line L 36-24-124 was more near to unity followed by M 7-35-12-1. standard check DS 30 not only produced poorest seed yield but had very less regression coefficient value (0.585) which indicated that variety is most suited to special type of environment (Table-6).The maximum value of regression coefficient was estimated in mutant Dc 1525421 (b=1.299) which showed that the line is most suited for rich environment. Standard deviation to regression (Sd^2) values were not higher and less than unity and ranged from 0.107 to 0.390. Mutant line M 7-35-12-1 had minimum value and standard check Ds 30 with highest value of (Sd2). The other three mutant lines which showed higher seed yield than the grand mean also had low standard deviation values less than Ds 30.

Velu and Shunmugavalli (2005), Shim *et. al* (2003) and Finley and Wilkinson (1963) computed and interpreted interaction of environments x genotypes in different ways. Finley and Wilkinson (1963) estimated for each variety a linear regression of its yield on the mean yield of all varieties for each location. Accordingly a stable variety is the one for which the regression coefficient does not differ from zero. (i.e. b=0 with in the limits of sampling error) and thus, stability is defined as consistency in performance of a variety over varying environment. However Eberhert and Russell (1966), Rajput *et al.*.(1998), Sarwar *et al. (*2003) and Saleem *et al*. (2002) considered regression coefficient (b) as parameter of response and standard deviation to regression (Sd^2) as the parameter of stability. Accordingly b value near to 1.0 indicates less response to environmental changes and hence more adaptive-ness. A high value of b will mean that variety is more responsive to rich environment. Such variety may therefore be recommended only for highly favorable environments, say under high fertility conditions. If b value is negative then variety may be grown only in poor environment. Thus a genotype with unit regression coefficient (b) and the deviation not significantly different from zero (Sd^2=o) is said to be the stable genotype.

Overall genotype M7-35-12-1 produced highest seed yield at all locations individually except during 2010 at Faisalabad when it achieved third position, however there was no significant differences in second and third position. Mean of five locations indicated the superiority of M7-35-12-1 by producing 52% higher seed yield as compared to standard check DS 30 and 19.24% than grand total. The regression coefficient (b) value estimated in M 7-35-12-1 was although not equal to unity but near to unity and its standard deviation to regression (.107) value was also not very high but lowest to all other genotypes under study. Moreover, this genotype had less maturity period

(125 days) as compared to 200 days and it can easily be harvested in one cutting operation before cultivation of wheat.

From the facts given above it may be concluded that early mutant of castor M 7-35-12-1 may be cultivated successfully for obtaining sustainable and stable yield over a variety of environment. It is further stated that a potential and economically a crop of castor which required less water and other inputs in the form of fertilizer or insecticide can be raised with less period of time without disturbing the due planting of next Rabi crop and may be best fitted in our existing cropping system.

Table 1. Weather data from 2007 – 2010 of Faisalabad region.

Climatic factor/year	**2007**	**2008**	**2009**	**2010**
Mean maximum temperature	37.20	37.00	37.82	36.92
Mean minimum temperature	27.54	26.7	27.07	26.94
Mean Highest Relative Humidity	93.14	92.71	90.00	90.07
Mean Lowest Relative Humidity	35.14	36.42	25.00	32.85
Rainfall during growing period	255.00	491.6	241.1	644.3

Table 2. Pedigree and salient features of castor mutants.

Sr.#	**Genotypes**	**Parent**	**Dose (gamma rays)**	**Days to mature**	**Height (cm)**	**100 Seed Wt. (g)**
1.	M7-35-12-1	DS 30	500 Gy	125	158.45	27.1
2.	M7-35-1-2	DS 30	500 Gy	124	177.1	25.3
3.	L57-32-784	C 176	300 Gy	143.5	207.6	22.0
4.	L36-24-124	DC 30	400 Gy	145	172.6	20.65
5.	DC 1525421	DC 15	500 Gy	126.5	250.1	27.10
6.	DC 15M271211	DC 15	500 Gy	128	181.4	27.0
7.	DS 30	Standard	-	200	234.6	26.6

Table 3. Performance of castor genotypes in different experiments 2007-2010. (Seed yield kg ha^{-1})

S.#	Genotype	Faisalabad 2007	Faisalabad 2008	Faisalabad 2009	Faisalabad 2010	Shortkot 2010	Mean
1.	M7-35-12-1	3088 A	3789 A	1742 A	2437 B	2824 A	2776 A
2.	M7-35-1-2	2664 ABC	2835 D	1368 B	2755 A	2726 A	2470 BC
3.	L5732784	2396 BCD	3687 AB	1448 B	2519 B	2706 A	2551 B
4.	L3624124	2890 AB	3322 C	1675 A	1985 C	1994 C	2373 C
5.	DC 1525421	2651 ABC	3511 BC	1200 C	1699 D	1561 D	2124 D
6.	DC15M271211	2200 CD	3542 B	1384 B	2004 C	1759 CD	2178 D
7.	DS 30 (Standard check)	2032 D	1901 E	788 D	2087 C	2317 B	1825 E

Table 4. Analysis of variance for seed yield (kg/ha) of castor genotypes.

K Value	**Source**	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**
1	Replication	2	120379.139	60189.570	1.9158 NS
2	Factor (A) *Genotypes*	6	8844282.360	1474047.060	46.9187 **
3	Factor (B) *Environments*	4	37636944.331	0409236.083	299.4944 **
4	A x B	24	10462788.509	435949.521	13.8762 **
5	Error	68	2136360.608	31417.068	
	Total	104	59200754.947		

Table 5. Pooled analysis of variance for seed yield (kg/ha) of castor genotypes.

Source	df	S.S.	M.S.	F Value
Total	34	19034368.000	559834.375	
Environment	4	12602386.000	3150596.500	23.386 **
Varieties	6	2935024.000	489170.656	3.631 **
Var. x Env.	24	3496958.000	145706.578	1.082 NS
Env. + Var. x Env.	28	16099344.000	574976.562	4.268 **
Env. <Lin>	1	12602381.000	12602381.000	93.545 **
Var. x Env. <Lin>	6	667828.750	111304.789	0.826 NS
Pooled Dev.	21	2829134.250	134720.672	4.179 **
Pooled Error	70	2256739.750	32239.139	

Table 6. Stability parameters for seed yield of 7 castor genotypes tested over 5 locations.

Sr.#	Genotypes	Mean	% increase over standard check Ds 30	Regression coefficient (b)	Standard deviation to regression (Sd^2)
1.	M7-35-12-1	2776 A	52.10	1.118	0.107
2.	M7-35-1-2	2470 BC	35.34	0.769	0.295
3.	L57-32-784	2551 B	39.78	1.148	0.214
4.	L36-24-124	2373 C	30.02	0.950	0.245
5.	DC 1525421	2124 D	16.38	1.299	0.309
6.	DC 15M271211	2178 D	19.34	1.132	0.269
7.	DS-30	1825 E	-	0.585	0.390

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