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Estimation of genetic variability, correlations and path coefficients for seed yield contributors in castor (*Ricinus communis* L.)

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Abstract

Castor is one of neglected African oil crops with little research attention in Nigeria. In the present research, eighty-six castor genotypes were evaluated at three locations in Niger State, Nigeria. The aim was to estimate the extent of genetic variability and also to examine the associations among the seed yield and its components. The treatments were laid out in an Alpha Lattice Design with three replications. The results revealed significant effects of genotypes on most of the studied traits. Days to 50% flowering ranged between 34 days and 125 days, and had a mean of 69.21 days. The minimum of 7.33 g and maximum of 64.12 were recorded for 100 seed weight. Seed yield ranged from 144.45 $Kgha^{-1}$ to 1 349.92 $Kgha^{-1}$ with the average yield of 646.04 $Kgha^{-1}$. Spike length and 100 seeds weight showed a high Genotypic Coefficient of Variation (GCV) and also high Phenotypic Coefficient of Variation (PCV). Significant positive correlations were observed between the seed yield and plant height at flowering, branches per plant, length of spike, spike per plant, days to maturity and 100 seeds weight. The path coefficient analysis revealed positive direct effects of seedling establishment, spike length, spikes per plant, plant height at first raceme maturity, days to first raceme maturity and 100 seeds weight on the seed yield. Highest positive direct effect on seed yield was recorded in spike length, followed by spikes per plant and seed weight, respectively. Significant positive correlations and high positive direct effect were observed between spike length, spikes per plant and seed weight. The findings revealed the importance of spike characters for the selection of desirable castor genotypes for increased seed yield.

Key words: Castor, Correlation, Direct effects, Path analysis, Traits association, Variability.

INTRODUCTION

Castor oil plant (*Ricinus communis* L.) is one of neglected African crops with high economic values (Gana *et al*., 2013). The crop has been demonstrating its economic potentials around the world, contributing notable foreign exchange credits to economy of many countries, including India, Brazil and China (Ibeagha and Onwualu, 2015). The oil extracted from castor seed is very critical to many industrial applications because of its ability to form many important derivatives (Ogunniyi, 2006). Demands for castor seed/oil in the international market has recently kept on increasing because of its applications in pharmaceutical industries, rubber/plastic industries and lubricants/ biodiesel industries (Mutlu and Meier, 2010). In Southern part of Nigeria, a food condiment (*Ogiri*) among the Igbo tribe is produced from castor seeds (Gana, 2015). The residual meal of castor seed, after detoxification by boiling, could be used as supplement feed in preparation of broiler finishing diets without any harmful effects (Ani and Okorie, 2009). Also, the meal (autoclaved) could be used in place of the soybean meal in sheep rations. Organic fertilizer produced from castor meal was reported to have advantage of high nitrogen content, fast mineralization and anti-nematode effects (Lima *et al*., 2011). Despite the huge economic benefits, castor genetic improvement in Nigeria has not been receiving much attention.

Presence of genotypic effects on the variability in a germplasm is the basis for any genetic improvement (Zheng *et al.,* 2010). It is therefore, important to examine the range of genetic variations within the species of any crop. Studies on partitioning of phenotypic variability into genetic and non-genetic (environment) components have long been proposed (Shivanna, 2008). The genetic component indicates the relative magnitude of genotypic variation, which conditions the extent of heritable portion of the variability in the germplasm. Furthermore, most of the traits of interest to breeders are traits with complex interactions of a number of components. Understanding the relationship among these components is highly important in a selection programme. Character relationship derived by correlation coefficient forms the basis for selecting the desirable plant and thus assisting in the determination of relative influence of various contributory traits on seed yield. Quantifying the contribution of yield components to grain yield, in order to determine if the interaction is direct or indirect, is also of high interest to breeders. Path coefficient analysis is an extension of regression analysis that is used to quantitatively examine the direct and indirect contributions of yield components to grain yield. In the present study, genetic variability, correlations, and direct/indirect effects were estimated for nine yield-contributory traits of castor, aiming at initiating a breeding programme for seed yield improvement of the crop.

MATERIALS AND METHODS

The castor genetic materials used for this study were obtained from castor research programme of National Cereals Research Institute (NCRI) Badeggi, Nigeria. The materials comprised of 39 local and 47 exotic collections presented in Table 1 and Table 2. The eighty-six (86) castor genotypes were evaluated at three locations in Nigeria (Mokwa - Lat. 9^o 12'N, Long. 5^o 20'E; Badeggi - Lat. 9°45'N, long. 6°07'E and Minna - Lat. 9^o 36'50"N, Long. 6^o 33'25"E). The treatments were laid out in an Alpha Lattice design with three replications. The plot size was 3 m by 1.5 m with inter-row and intra-row spacing of 75 cm by 75 cm. Two seeds per hole were planted and later thinned to one seedling per hole three to four weeks after planting. NPK fertilizer at 30:30:30 was applied one month after planting and weeding was done three times during the experiment. Morphological data were taken according to India (2004) castor descriptor. The parameters considered include: seedling establishment counts (%), number of days to first spike flowering, number of days to first spike maturity, number of branches per plant, number of spikes per plant, plant height at maturity, seed yield per plot (kg), 100 seeds weight (g). The data were analyzed using random model procedure of Plant Breeding Tools (PBTools 1.4, 2014). The significant effects of all sources of variation were verified using Likelihood ratio test. Excel format was used to estimate path coefficients for direct and indirect effects according to Akintunde (2012). The models for testing the significant effects of each variance component are as follows.

Genotypic effect:

Model 1: Trait ~ 1 + (1|Treatment) + (1|Trial) + (1|Rep:Trial) + (1|Rep:Block:Trial) + (1|Treatment:Trial)

Model 2: Trait ~ 1 + (1|Trial) + (1|Rep:Trial) + (1|Rep:Block:Trial) + (1|Treatment:Trial)

Environment effect:

Model 1: Trait ~ 1 + (1|Treatment) + (1|Trial) + (1|Rep:Trial) + (1|Rep:Block:Trial) + (1|Treatment:Trial)

Model 2: Trait ~ 1 + (1|Treatment) + (1|Rep:Trial) + (1|Rep:Block:Trial) + (1|Treatment:Trial)

Genotype by environment effect:

Model 1: Trait ~ 1 + (1|Treatment) + (1|Trial) + (1|Rep:Trial) + (1|Rep:Block:Trial) + (1|Treatment:Trial)

Model 2: Trait ~ 1 + (1|Treatment) + (1|Trial) + (1|Rep:Trial) + (1|Rep:Block:Trial)

The magnitude of the effects was determined using Robert & Raftery (1995) procedure.

Genotypic variance (σ^2_g) = $\sigma^2_e + r\,\sigma^2_g l + r\sigma^2_g$

Genotype by Location variance ($\sigma^2 ge$) = $\sigma^2_e + r\,\sigma^2_g l$

Phenotypic variance (σ^2_p) = $\sigma^2_g + \sigma^2 ge / m_h + \sigma^2 / P_h$ [Piepho & Möhring, 2007] - for incomplete block design)

$$m_h = \frac{n}{\sum_{i=1}^{n} 1/m_i} \qquad P_h = \frac{n}{\sum_{i=1}^{n} 1/P_i}$$

Genotypic coefficient of variation (GCV) % =

$$\frac{\text{Genotypic standard deviation}}{\text{Experimental mean}} \times 100$$

Phenotypic coefficient of variation (PCV) % =

$$\frac{\text{Phenotypic standard deviation}}{\text{Experimental mean}} \times 100$$

[GCV and PCV were classified into Low (0-10%), Moderate (10-20%) and as High (20% and above) according to Shivanna (2008)].

RESULTS AND DISCUSSION

Significant effects of the sources of variation is presented in Table 3. Effect of genotypes was significant for all the studied traits except branches per plant and plant height at raceme maturity, indicating the presence of considerable genetic variability in the germplasm for most of the traits. Significant interactions of genotypes by locations were observed for the height at flowering (cm), branches per plant, days to maturity, seed weight and seed yield (Table 3). This showed the possibility of exploiting different environments for development of location specific castor varieties from the genotypes.

Table 1. Name and seed physical characteristics of the local castor germplasm included in the study.

NCRI No.	Place of collection	Seed shape	Seed colour	Seed mottle	Caruncle	Seed size
ACC.004	Benue	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.005	Yobe	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.006	UAM/Benue	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.007	IAR/Kaduna	Elongated	Brown	Less conspicuous	Conspicuous	Medium
ACC.008	IAR/Kaduna	Elongated	Maroon	Conspicuous	Conspicuous	Medium
ACC.009	IAR/Kaduna	Square	White	Conspicuous	Conspicuous	Large
ACC.010	Kat./Benue	Oval	Dark Chocolate	Less conspicuous	Conspicuous	Small
ACC.012	Ankpa/Kogi	Oval	Brown	Less conspicuous	Conspicuous	Small
ACC.015	Ankpa/Kogi	Square	Dark Chocolate	Conspicuous	Conspicuous	Large
ACC.016	Dekina/Kogi	Square	White	Conspicuous	Conspicuous	Large
ACC.017	Dekina/Kogi	Square	White	Conspicuous	Conspicuous	Small
ACC.018	Dekina/Kogi	Elongated	Brown	Less conspicuous	Conspicuous	Medium
ACC.019	Dekina/Kogi	Elongated	Brown	Less conspicuous	Conspicuous	Small
ACC.022	Ofu/Kogi	Oval	Dark Chocolate	Less conspicuous	Conspicuous	Small
ACC.024	Lokoja/Kogi	Ovall	Maroon	Conspicuous	Conspicuous	Large
ACC.026	Ilorin/Kwara	Ovall	Brown	Less conspicuous	Conspicuous	Small
ACC.027	Ilorin/Kwara	Ovall	Maroon	Less conspicuous	Conspicuous	Medium
ACC.028	Asa/Kwara	Elongated	Brown	Less conspicuous	Conspicuous	Medium
ACC.029	Ilorin/Kwara	Elongated	Brown	Conspicuous	Conspicuous	Small
ACC.031	Asa/Kwara	Square	Brown	Less conspicuous	Less conspicuous	Small
ACC.032	Bida/Niger	Oval	Dark Chocolate	Conspicuous	Conspicuous	Large
ACC.033	Badeggi/Niger	Elongated	Brown	Conspicuous	Conspicuous	Medium
ACC.034	Badeggi/Niger	Ovall	Brown	Less conspicuous	Less conspicuous	Small
ACC.035	Bida/Niger	Ovall	B. Red	Conspicuous	Less conspicuous	Medium
ACC.036	Badeggi/Niger	Ovall	Dark-chocolate	Less conspicuous	Conspicuous	Medium
ACC.036M	Badeggi/Niger	Ovall	Dark-chocolate	Less conspicuous	Conspicuous	Medium
ACC.039	Ikoyi/Oyo	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.040	Ogbomosho	Square	White	Less conspicuous	Conspicuous	Large
ACC.041	Alaja/Oyo	Square	White	Less conspicuous	Conspicuous	Large
ACC.042	Alaja/Oyo	Oval	B. Red	Conspicuous	Less conspicuous	Small
ACC.043	Alaja/Oyo	Oval	Black	Less conspicuous	Conspicuous	Large
ACC.044	Ogbomosho	Square	White	Less conspicuous	Conspicuous	Large
ACC.045	Ogbomosho	Square	White	Less conspicuous	Less conspicuous	Large
ACC.046	Ifelodun/Kwara	Oval	Brown	Conspicuous	Conspicuous	Small
ACC.047	Ede/Osun	Square	Black	Less conspicuous	Conspicuous	Large
ACC.048	Osogbo/Osun	Square	White	Less conspicuous	Conspicuous	Large
ACC.050	Joro/Kwara	Square	White	Less conspicuous	Conspicuous	Large
ACC.051	Asa/Kwara	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.102	Ilorin/Kwara	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.103	Bida	Oval	Brown	Less conspicuous	Less conspicuous	Small

Table 2. Name and seed physical characteristics of the exotic castor germplasm included in the study.

NCRI No.	Source	Seed shape	Seed colour	Seed mottle	Caruncle	Seed size
ACC.001	Brazil/IAR	Square	Maroon	Less conspicuous	Conspicuous	Large
ACC.002	Brazil/IAR	Oval	Dark Chocolate	Conspicuous	Conspicuous	Small
ACC.003	Brazil/IAR	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Small
ACC.052	Turkey	Oval	Brown	Less conspicuous	Less conspicuous	Medium
ACC.053	Turkey	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Medium
ACC.054	Turkey	Elongated	B. Red	Less conspicuous	Less conspicuous	Large
ACC.055	Turkey	Oval	B. Red	Less conspicuous	Less conspicuous	Medium
ACC.056	Turkey	Oval	B. Red	Conspicuous	Less conspicuous	Medium
ACC.057	India	Oval	B. Red	Conspicuous	Less conspicuous	Medium
ACC.058	Turkey	Oval	Brown	Less conspicuous	Less conspicuous	Small
ACC.059	Turkey	Elongated	Dark Chocolate	Conspicuous	Conspicuous	Large
ACC.060	India	Oval	B. Red	Conspicuous	Less conspicuous	Large
ACC.061	Brazil	Elongated	B. Red	Conspicuous	Conspicuous	Small
ACC.062	India	Elongated	B. Red	Conspicuous	Conspicuous	Medium
ACC.063	India	Elongated	B. Red	Less conspicuous	Less conspicuous	Medium
ACC.064	India	Elongated	Dark Chocolate	Conspicuous	Conspicuous	Large
ACC.065	India	Oval	B. Red	Less conspicuous	Less conspicuous	Small
ACC.066	India	Oval	Dark Chocolate	Conspicuous	Conspicuous	Medium
ACC.067	Algeria	Elongated	B. Red	Conspicuous	Conspicuous	Large
ACC.068	Cuba	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Medium
ACC.069	Cuba	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Small
ACC.070	Puerto	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Small
ACC.071	U.S	Elongated	Dark Chocolate	Less conspicuous	Less conspicuous	Small
ACC.072	Panama	Oval	Brown	Conspicuous	Less conspicuous	Small
ACC.073	Cuba	Oval	Dark Chocolate	Less conspicuous	Conspicuous	Medium
ACC.075	Argentina	Elongated	Dark Chocolate	Less conspicuous	Conspicuous	Medium
ACC.076	Iran	Elongated	Dark Chocolate	Conspicuous	Conspicuous	Small
ACC.077	Iran	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Small
ACC.080	Brazil	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Medium
ACC.081	India	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Medium
ACC.083	India	Elongated	B. Red	Conspicuous	Conspicuous	Large
ACC.085	Iran	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Medium
ACC.087	India	Elongated	B. Red	Less conspicuous	Conspicuous	Large
ACC.088	S. Africa	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Medium
ACC.089	S. Africa	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Large
ACC.090	S. Africa	Elongated	B. Red	Less conspicuous	Conspicuous	Large
ACC.091	S. Africa	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Large
ACC.093	S. Africa	Oval	B. Red	Conspicuous	Conspicuous	Large
ACC.094	Russia	Oval	Brown	Less conspicuous	Less conspicuous	Large
ACC.095	U.S	Oval	Brown	Less conspicuous	Less conspicuous	Medium
ACC.096	U.S	Oval	B. Red	Conspicuous	Less conspicuous	Large
ACC.097	Colombia	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Medium
ACC.098	Ecuador	Elongated	Dark Chocolate	Conspicuous	Less conspicuous	Medium
ACC.099	U.S.	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Medium
ACC.100	U.S.	Oval	Dark Chocolate	Conspicuous	Less conspicuous	Medium
ACC.101	U. S.	Oval	Dark Chocolate	Less conspicuous	Less conspicuous	Medium

The genotypic effect was found to be more on most of the traits ranging from very strong effects (BIC2–BIC1>10) to strong (BIC2–BIC1; 6-10) (Robert & Raftery, 1995). Similar findings were reported by Laureti (1988).

Estimates for variance components are presented in Table 4. Seedling establishment varied between 0.00 and 100% with average of 71.35% (Table 4). Days to 50% flowering ranged between 34 days and 125 days, and had mean of 69.21 days. Number of branches per plants ranged between 1 and 15, with average value of 6.15. Minimum of 7.33g and maximum of 64.12

were recorded for 100 seed weight. Seed yield ranged from 144.45 Kgha^{-1} to 1349.92 Kgha^{-1} with average yield of 646.04 Kgha^{-1}. Genotypic variance ($\varepsilon^2 g$) was higher than variance due to genotype by environment interaction ($\varepsilon^2 g\times e$) in all the traits except in height at flowering, supporting the high magnitude effects of genotype showed in Table 3 and also indicating validity of genotype ranking using genotype means across the environments (Gomez and Gomez, 1984). Two traits (spike length and seed weight) showed high genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV). Moderate GCV were observed in ESTAB, days to flowering and spikes per plant. Height at flowering, branches per plant, height at first spike maturity, days to maturity and seed yield registered low GCV. Similar assessments of castor genotypic and phenotypic variability have been reported by Allan *et al.* (2008), Rao *et al.* (2006), Golakia *et al.* (2007) and Zheng *et al.* (2010). Patel and Jaimini (1988) reported moderate to high genotypic co-efficient of variation irrespective of environments for most of the economic traits in castor. In the contrary, a low GCV was recorded for six out of ten traits evaluated in the present research. Golakia *et al.* (2015) observed sufficient genetic variability for most of characters in castor including seed yield per plant.

Table 3. Effects of all components of variance for ten agronomic traits in castor at three locations.

Parameters	Genotypic effect		Environmental effect		Genotype×Environ.	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Establishment (%)						
AIC	7832.20	7894.12	7832.20	7830.20	7832.20	7830.21
BIC	7865.53	7922.69	7865.53	7858.77	7865.53	7858.78
LogLik.	-3909.10	-3941.06	-3909.10	-3909.10	-3909.10	-3909.11
Chisq.	63.92		0.001		0.01	
Df	1		1		1	
Pr (>Chisq)	0.00		0.98		0.92	
$BIC_2 – BIC_1$	57.16		-6.76		-6.75	
Days to flowering						
AIC	6749.18	6833.60	6749.18	6754.74	6749.18	6747.31
BIC	6782.52	6862.18	6782.52	6783.31	6782.52	6775.88
LogLik.	-3367.59	-3410.80	-3367.59	-3371.37	-3367.59	-3367.65
Chisq.	86.42		7.55		0.12	
Df	1		1		1	
Pr (>Chisq)	0.00		0.01		0.73	
$BIC_2 – BIC_1$	79.66		0.79		-6.64	
Height at flowering (cm)						
AIC	7647.90	7659.34	7647.90	7654.52	7647.90	7659.26
BIC	7681.24	7687.92	7681.24	7683.09	7681.24	7687.84
LogLik.	-3816.95	-3823.67	-3816.95	-3821.26	-3816.95	-3823.63
Chisq.	13.44		8.62		13.36	
Df	1		1		1	
Pr (>Chisq)	0.00		0.00		0.00	
$BIC_2 – BIC_1$	6.68		1.85		6.60	
Branches per plant						
AIC	3017.58	3016.54	3017.58	3042.61	3017.58	3058.38
BIC	3050.93	3045.12	3050.93	3071.19	3050.93	3086.97
LogLik.	-1501.79	-1502.27	-1501.79	-1515.30	-1501.79	-1523.19
Chisq.	0.96		27.03		42.80	
Df	1		1		1	
Pr (>Chisq)	0.33		0.00		0.00	
$BIC_2 – BIC_1$	-5.81		20.26		36.04	
Spike length (cm)						
AIC	5584.31	5596.32	5584.31	5591.28	5584.31	5582.72
BIC	5617.65	5624.90	5617.65	5619.87	5617.65	5611.30
LogLik.	-2785.15	-2792.16	-2785.15	-2789.64	-2785.15	-2785.36

Table 3 (Continue). Effects of all components of variance for ten agronomic traits in castor at three locations.

Parameters	Genotypic effect		Environmental effect		Genotype×Environ.	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Chisq.	14.02		8.98		0.41	
Df	1		1		1	
Pr (>Chisq)	0.00		0.00		0.52	
$BIC_2 - BIC_1$	7.25		2.22		-6.35	
Spikes per plant						
AIC	3160.82	3192.03	3160.82	3158.82	3160.82	3158.86
BIC	3194.15	3220.60	3194.15	3187.39	3194.15	3187.43
LogLik.	-1573.41	-1590.02	-1573.41	-1573.41	-1573.41	-1573.43
Chisq.	33.22		0.00		0.05	
Df	1		1		1	
Pr (>Chisq)	0.00		0.98		0.83	
$BIC_2 - BIC_1$	26.45		-6.76		-6.72	
Height at maturity (cm)						
AIC	8012.37	8014.09	8012.37	8020.26	8012.37	8011.48
BIC	8045.68	8042.65	8045.68	8048.82	8045.68	8040.04
LogLik.	-3999.19	-4001.05	-3999.18	-4004.13	-3999.19	-3999.74
Chisq.	3.73		9.89		1.11	
Df	1		1		1	
Pr (>Chisq)	0.05		0.00		0.29	
$BIC_2 - BIC_1$	-3.03		3.14		-5.28	
Days to maturity						
AIC	6757.06	6780.94	6757.06	6755.71	6757.06	6762.77
BIC	6790.37	6809.50	6790.37	6784.26	6790.37	6791.33
LogLik.	-3371.53	-3384.47	-3371.53	-3371.85	-3371.53	-3375.39
Chisq.	25.88		0.65		7.71	
Df	1		1		1	
Pr (>Chisq)	0.00		0.42		0.00	
$BIC_2 - BIC_1$	19.13		-6.11		0.96	
Seed weight (g)						
AIC	6287.97	6306.50	6287.97	6298.86	6287.97	6306.50
BIC	6321.28	6335.06	6321.28	6327.42	6321.28	6331.06
LogLik.	-3136.98	-3147.25	-3136.98	-3143.43	-3136.98	-3147.25
Chisq.	20.54		12.90		20.54	
Df	1		1		1	
Pr (>Chisq)	0.00		0.00		0.00	
$BIC_2 - BIC_1$	13.78		6.14		9.78	
Seed yield (kg/ha)						
AIC	11121.66	11125.35	11121.66	11124.09	11121.66	11218.89
BIC	11154.98	11154.99	11154.98	11152.65	11154.98	11247.45
LogLik.	-5553.83	-5556.67	-5553.82	-5556.05	-5553.83	-5603.45
Chisq.	5.69		4.43		99.23	
Df	1		1		1	
Pr (>Chisq)	0.02		0.04		0.00	
$BIC_2 - BIC_1$	0.01		-2.33		94.47	

AIC: Akaike's information criterion, BIC: Bayesian information criterion, LogLik.: Loglikelihood, Df: Degree of freedom between the models.

Significant positive correlations were observed between the seed yield and height at flowering, branches per plant, length of spike, spike per plant, days to maturity and 100 seed weight (Table 5). Significant positive correlations were recorded between seedling establishment and height at flowering, height at maturity, seed weight. Spike length showed a positive and significant correlation to height at maturity. Significant negative correlations were recorded between the spike length and height at flowering, and branches per plant (Table 5). The path coefficient analysis revealed positive direct effects of six traits out of the nine yield contributory traits evaluated (Table 6). Highest positive direct effect on seed yield was recorded in spike length, followed by spikes per plant, seed weight, days to maturity, seedling establishment, and height at maturity, respectively (Table 6). Negative direct effects on seed yield were observed for days to flowering, height at flowering and branches per plant. The significant correction and positive direct effects observed in spike length, spikes per plant and seed weight indicated the true relationship between the seed yield and the mentioned traits, thus direct selection for the traits would likely be effective in increasing seed yield of castor. The significant positive correlation and negative direct effects observed for branches per plant may be due to the indirect effects through spikes per plant (Table 6). Negative indirect effect through spike length was observed for seed weight, suggesting that the longer the spike the lesser the seed weight.

Table 4. Combined mean values, minimum, maximum and variance components for all the traits studied.

Parameters	Mean±SE	Min.	Max.	σ^2g	$\sigma^2g\times e$	σ^2_P	GCV	PCV
ESTAB	71.35±4.82	0	100	154.23	1.66	200.99	17.41	19.87
DF	69.21±6.47	34	125	51.73	1.62	64.88	10.39	11.64
HF	71.79±8.92	25	333.33	46.34	54.48	99.35	9.48	13.88
SL	5.90±0.56	1	14	3.5	0.82	7.37	31.71	46.01
BPP	19.04±2.23	9	98	0.37	0.02	0.59	3.20	4.03
SPP	6.15±1.45	1	15	0.39	0.21	0.89	10.16	15.25
HM	113.70±12.01	51.2	246	28.92	24.67	99.93	4.73	8.79
DM	109.81±10.46	80	166	24.91	14.77	42.56	4.55	5.94
SW	24.91±3.41	7.33	65.12	74.28	12.74	84.47	34.60	36.90
SY	646.04±15.76	144.45	1549.92	2607.67	10224.27	7656.79	9.80	13.55

σ^2g: Genotypic variance, υ_{BLUP}: Mean variance of a difference of the BLUP of g_i, $\sigma^2g\times e$: Variance due to interaction of genotype and environment, σ^2_P: Phenotypic variance, GCV: Genotypic coefficient variance, PCV: Phenotypic coefficient variance, H^2: Broad sense heritability, GA: Genetic advance, GAM: Genetic advance as percentage of mean;

Parameters: ESTAB: Seedling establishment (%), DF: Days to flowering, HF: Height at first spike flowering (cm), SL: Spike length (cm), BPP: Branches per plant, SPP: Spikes per plant, HM: Height at first raceme maturity (cm), DM: Days to first raceme maturity, SW: 100 seeds weight, SY: Seed yield ($Kgha^{-1}$).

Table 5. Genotypic coefficients of correlation for nine yield component traits studied among 86 castor accessions.

Parameters	SY ($Kgha^{-1}$)	ESTAB	DF	HF (cm)	BPP	SL (cm)	SPP	HM (cm)	DM
SY	1								
ESTAB	0.278	1							
DF	-0.069	0.303	1						
HF	0.603**	0.433**	0.077	1					
BPP	0.517**	-0.002	0.055	0.308	1				
SL	0.769**	0.039	0.372*	-0.423**	-0.386*	1			
SPP	0.598**	0.227	0.296	0.051	0.020	0.020	1		
HM	-0.212	0.330*	0.285	-0.158	-0.305	0.734**	-0.026	1	
DM	0.395*	0.212	0.253	0.211	0.500**	-0.213	0.272	-0.137	1
SW	0.547**	0.498**	0.099	0.863**	0.339*	-0.223	-0.119	0.021	0.192

Note: Parameters: ESTAB: Seedling establishment (%), DF: Days to flowering, HF: Height at first spike flowering (cm), SL: Spike length (cm), BPP: Branches per plant, SPP: Spikes per plant, HM: Height at first raceme maturity (cm), DM: Days to first raceme maturity, SW: 100 seeds weight, SY: Seed yield ($Kgha^{-1}$).

*: Significant at 0.05% level.

**: Significant at 0.01% level.

Table 6. Genotypic path coefficients of direct (bold diagonal) and indirect effects of nine traits on seed yield of 86 castor accessions.

Parameters	ESTAB	DF	HF (cm)	BPP	SL (cm)	SPP	HM (cm)	DM	SW (g)
ESTAB	**0.097**	-0.002	-0.034	0.006	0.031	0.005	0.037	0.016	0.013
DF	0.029	**-0.046**	-0.006	-0.001	0.045	0.007	0.032	0.019	0.007
HF	0.042	-0.006	**-0.077**	-0.007	-0.006	0.001	-0.118	0.026	0.051
BPP	-0.001	-0.003	-0.024	**-0.024**	-0.005	0.282	-0.294	0.061	0.022
SL	0.004	-0.002	0.386	0.089	**0.623**	0.001	0.093	-0.016	-0.045
SPP	0.022	-0.002	-0.004	0.421	0.032	**0.51**	-0.025	0.041	-0.008
HM	0.032	-0.002	0.432	0.067	0.053	-0.13	**0.062**	-0.011	0.026
DM	0.021	-0.002	-0.016	-0.019	-0.003	0.016	-0.013	**0.176**	0.018
SW	0.048	-0.003	-0.067	-0.008	-0.003	-0.103	0.002	0.075	**0.456**

Note: Parameters: ESTAB: Seedling establishment (%), DF: Days to flowering, HF: Height at first spike flowering (cm), SL: Spike length (cm), BPP: Branches per plant, SPP: Spikes per plant, HM: Height at first raceme maturity (cm), DM: Days to first raceme maturity, SW: 100 seeds weight.

The direct effects of seed weight, spike length, and positive-indirect effect of the spikes per plant on seed yield revealed the importance of spikes characters as yield contributors in castor. The results reported here is similar to findings in earlier studies. Ramesh and Venkate (2001) recorded strong correlation between seed yield and plant height to primary spike, and length of spike. The number of capsules per plant and 100 seed weight had direct and positive effects on seed yield (Ramesh and Venkate, 2001). Torres *et al.* (2015) reported that direct and indirect selections of genotypes with plant height, stem girth, branches per plant and seed weight are effective to select genotypes with high seed oil. Aswani *et al*. (2003) reported positive and significant genotypic relationships among seed yield, seed weight, number of days to flowering, number of days to maturity and plant height. Deepika and Tummala (1981) reported direct effects of capsules per plant, spikes per plant and days to flowering on the seed yield of castor.

CONCLUSION

The results of the study revealed considerable genetic variability in the germplasm evaluated for most of the traits. Significant positive correlations were observed between the seed yield and height at flowering, branches per plant, length of spike, spike per plant, days to maturity and 100 seed weight. The path coefficient analysis revealed positive direct effects of six out of the nine traits studied on seed yield. Significant positive corrections and positive direct effects on seed yield were observed for spike length, spikes per plant and seed weight. Out of all the studied traits, spike characters are identified as most important traits in selecting desirable plants for higher seed yield in castor.

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