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DISSECTING THE ASSOCIATION OF YIELD AND ITS COMPONENT TRAITS THROUGH PHENOTYPIC AND GENOTYPIC CORRELATION AND PATH COEFFICIENT ANALYSIS IN ADVANCED BREEDING LINES OF CASTOR (*Ricinus communis* L.)

Rani R. Marad[1], Yashas D.L.[1], Yamanura[2*], Nishanth H.[3] and Aayushi Mittal[1]

[1]Department of Genetics and Plant Breeding, College of Agriculture, University of Agricultural Sciences, GKVK, Bengaluru – 560 065, Karnataka, India.

[2]AICRP on Castor, Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bengaluru – 560 065, Karnataka, India.

[3]Department of Genetics and Plant Breeding, University of Horticultural Sciences, Bagalkot – 587104, Karnataka, India.

*Corresponding author E-mail: yaman3181aug8@gmail.com

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ABSTRACT

The present study was undertaken to assess the association of yield and its attributing traits and to identify important traits contributing to yield among advanced breeding lines of castor (*Ricinus communis* L.). The experimental material was evaluated for ten quantitative traits, and analysis of variance, phenotypic and genotypic correlation coefficients, and path coefficient analysis were employed to understand the relationships among the traits and their contribution to yield per plant. Analysis of variance revealed highly significant differences among the genotypes for all the traits studied, indicating significant genotypic differences among the evaluated lines. Phenotypic correlation analysis revealed significant positive associations of yield per plant with plant height (0.369**), total spike length (0.545**), effective spike length (0.500**), number of spikes (0.495**) and number of capsules (0.531**), whereas days to maturity exhibited a significant negative association with yield per plant (-0.374**). At the genotypic level, plant height (0.430*), total spike length (0.643**), effective spike length (0.590**), number of spikes (0.684**) and number of capsules (0.595**) showed significant positive associations with yield per plant, while days to maturity exhibited a significant negative association (-0.633**). Path coefficient analysis was further employed to partition the correlations into direct and indirect effects. Number of capsules recorded the highest positive direct effect on yield per plant (0.4030), followed by effective spike length (0.3849), days to 50% flowering (0.2905) and number of spikes (0.2864). Plant height also showed a positive direct effect (0.1378), whereas number of nodes (-0.3260), days to maturity (-0.3141) and total spike length (-0.0919) exhibited negative direct effects. The residual effect was 0.3914, indicating that the traits included in the analysis accounted for approximately 60.86% of the variation in yield per plant. Overall, number of capsules, effective spike length and number of spikes emerged as key yield-contributing traits, highlighting their potential utility in selection for higher yield in castor.

***Key words*:** Castor, advanced breeding lines, path coefficient, phenotypic and genotypic correlation

Introduction

Castor (*Ricinus communis* L.), a member of the spurge family (Euphorbiaceae), is widely grown as an industrial, non-edible oilseed. It exhibits a monoecious, allogamous breeding behavior (2n = 20) with racemes partitioned into upper female flowers (30–50%) and lower male flowers (50–70%) (Weiss, 2000). Seed oil content typically spans 47–55%, with ricinoleic acid constituting the vast majority (80–90%) of the lipid fraction (Mubofu, 2016). The presence of a distinct hydroxyl group on the

C-12 position grants the oil elevated solubility and viscosity compared to other plant-derived lipids, driving its widespread use across diverse manufacturing sectors (Salunkhe and Desai, 1986).

Due to its versatile chemistry, castor oil is widely incorporated into lubricants, paints, surface treatments, cosmetics, drug formulations, biopolymers, nylon, aviation propellants and renewable fuels. In aerospace and defense systems, its ability to maintain stable viscosity across extreme thermal gradients flowing at temperatures down to –32 °C without degrading under high heat renders it a vital specialty lubricant. Furthermore, castor has gained traction in pharmacological research as a source of bioactive compounds; notably, the isolated triterpenoid lupeol exhibits proven anti-inflammatory, anticancer, antidiabetic, hepatoprotective and antiretroviral properties (Saleem, 2009); (Zhang *et al.*, 2015). These attributes affirm the crop's pivotal status in industrial chemistry as well as therapeutic discovery.

Yield is a complex quantitative trait influenced by the combined effects of several yield-attributing characters, making the understanding of their interrelationships essential for effective selection in crop improvement programmes (Grafius, 1956). Correlation analysis provides an insight into the strength and direction of associations among yield and its contributing traits, whereas path coefficient analysis further partitions these correlations into direct and indirect effects, thereby identifying traits that contribute most substantially to yield (Patel *et al.*, 2018b). Such information facilitates the identification of reliable selection criteria and helps breeders formulate effective selection strategies for improving yield potential (Oke, 2024). Therefore, the present study was undertaken to assess the association among yield and yield-attributing traits and to determine their direct and indirect contributions to yield in diverse castor accessions.

Materials and Methods

The present investigation was carried out at research plots (K-7 block) of All India Co-ordinated Research Project on Castor, Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bengaluru, located at 13° 05' N latitude, 77° 34' E longitude and altitude of 924 m from above mean sea level, which comes under Eastern Dry Zone of Karnataka. Basic experimental material consisted of 26 advanced breeding lines (ABLs)

The evaluation of 26 parental lines was carried out during the *rabi* 2025 in a Randomized Complete Block Design (RCBD) with two replications. Each parental entry was grown in a single-row plot of 6.0 m length accommodating 10 dibbles, maintaining an inter-row and intra-row spacing of 90 cm and 60 cm, respectively. A recommended fertilizer dose of 40:40:20 kg/ha of $N:P_2O_5:K_2O$ was applied, along with standard agronomic practices and plant protection measures to raise a healthy and uniform crop stand.

Observations were recorded on five randomly selected plants per entry across all the ABLs for 10 quantitative characters: days to 50% flowering, days to maturity, number of nodes, plant height, total spike length, effective spike length, number of spikes per plant, number of capsules, 100-seed weight and seed yield per plant. The mean values computed over the sampled plants for each entry were utilized for subsequent statistical analysis. Correlation and path coefficient analyses were performed using the 64-bit version of RStudio software to evaluate the associations among the studied traits and to assess the direct and indirect effects of yield-related traits on grain yield.

Results and Discussion

The analysis of variance (Table 1) revealed highly significant differences among the genotypes for all the ten traits studied, indicating the presence of substantial genetic variability among the castor advanced breeding lines. In contrast, the effect of replications was non-significant for all the traits, indicating that the experimental conditions across the replications were relatively uniform and that environmental variation between replications was minimal.

The significant genotypic variation observed for all the traits suggests the presence of substantial genetic

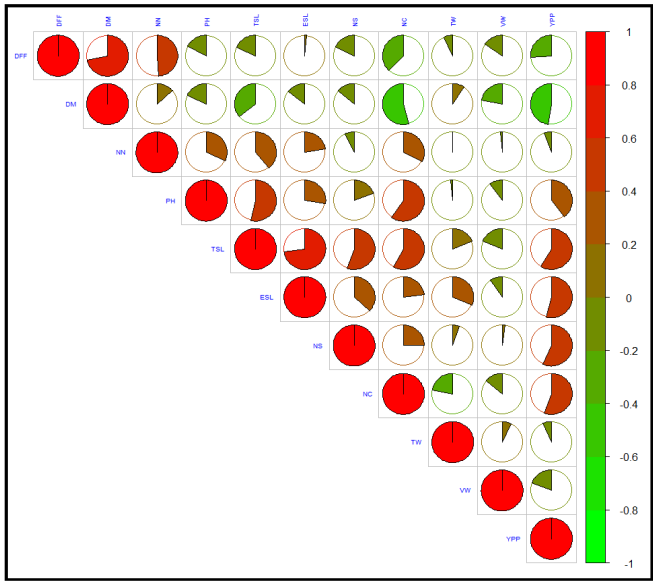


Fig. 1: Phenotypic correlation plot for yield and its attributing traits.

Table 1: Analysis of variance.

Source	df	Mean sum of square									
		DM	DFF	NN	PH	TSL	ESL	NS	NC	TW	YPP
Replication	1	9.308	0.308	0.727	93.340	80.676	79.262	0.222	21.918	6.231	19.120
Genotypes	25	82.212 **	145.908 **	4.696 **	452.730 **	172.025 **	175.549 **	3.660 **	276.201 **	10.520 **	632.400 **
Error	25	23.868	12.548	1.532	33.870	20.500	20.814	1.012	17.550	1.711	81.230
Total	51										

****** Significant at 1% (p = 0.01); **DM** - Days to maturity, **DFF** - Days to 50% flowering, **NN** - Number of nodes, **PH** - Plant height (cm), **TSL** - Total spike length (cm), **ESL** - Effective spike length (cm), **NS** - Number of spikes, **NC** - Number of capsules, **TW** - Test weight (g), **YPP** - Yield per plant (g)

variability among the evaluated breeding lines, providing scope for effective selection and genetic improvement of yield and its component traits in castor. Similar reports were also discussed by Patel *et al.*, (2018a); Godhani *et al.*, (2023) and Nagaraj *et al.*, (2025).

Phenotypic and genotypic correlation

Phenotypic and genotypic correlation coefficients of the attributing traits with yield per plant are presented in Table 2, while the correlation patterns among the studied traits are graphically depicted in Fig. 1. At the phenotypic level, plant height (0.369**) (Fig. 1), total spike length (0.545**), effective spike length (0.500**) number of spikes (0.495**) and number of capsules (0.531**) exhibited significant positive correlations with yield per plant. Days to maturity (-0.374**) showed a significant negative correlation with yield per plant, whereas days to 50% flowering (-0.019), number of nodes (-0.021) and test weight (-0.019) showed a non-significant negative correlation with yield per plant. At genotypic level, plant height (0.430*), total spike length (0.643**), effective spike length (0.590**), number of spikes (0.684**) and number of capsules (0.595**) exhibited significant positive correlations with yield per plant. Days to maturity (-0.633**) showed a significant negative correlation with yield per plant, whereas days to 50% flowering (-0.312), number of nodes (-0.115) and test weight (-0.129) showed a non-significant negative correlation with yield per plant.

The significant positive association of plant height, total spike length, effective spike length, number of spikes and number of capsules with yield per plant indicates that improvement in these traits may be associated with increased yield in the evaluated castor breeding lines.

Table 2: Phenotypic and genotypic correlation analysis in advanced breeding lines of castor.

Trait	Correlation	DM	DFF	NN	PH	TSL	ESL	NS	NC	TW	YPP
DM	**PC**	**1.000**	0.605**	0.038	-0.119	-0.282*	-0.123	-0.051	-0.426**	0.055	**-0.374****
	GC	**1.000**	0.887**	0.313	-0.275	-0.477*	-0.181	-0.295	-0.714**	0.145	**-0.633****
DFF	**PC**		**1.000**	0.457**	-0.156	-0.145	0.026	-0.159	-0.325*	-0.090	**-0.225**
	GC		**1.000**	0.547**	-0.193	-0.225	-0.004	-0.210	-0.438*	-0.050	**-0.312**
NN	**PC**			**1.000**	0.295*	0.363**	0.232	-0.105	0.289*	0.022	**-0.021**
	GC			**1.000**	0.364	0.430*	0.214	-0.007	0.378	-0.041	**-0.115**
PH	**PC**				**1.000**	0.505**	0.256	0.189	0.570**	-0.021	**0.369****
	GC				**1.000**	0.577**	0.292	0.196	0.627**	-0.010	**0.430***
TSL	**PC**					**1.000**	0.744**	0.449**	0.551**	0.181	**0.545****
	GC					**1.000**	0.707**	0.713**	0.616**	0.204	**0.643****
ESL	**PC**						**1.000**	0.301*	0.219	0.279*	**0.500****
	GC						**1.000**	0.464*	0.244	0.363	**0.590****
NS	**PC**							**1.000**	0.255	0.055	**0.495****
	GC							**1.000**	0.239	0.042	**0.684****
NC	**PC**								**1.000**	-0.210	**0.531****
	GC								**1.000**	-0.238	**0.595****
TW	**PC**									**1.000**	**-0.019**
	GC									**1.000**	**-0.129**

PC- Phenotypic correlation; **GC**- Genotypic correlation; ***** Significant at 5% (p = 0.05); ****** Significant at 1% (p = 0.01)
DM - Days to maturity, **DFF** - Days to 50% flowering, **NN** - Number of nodes, **PH** - Plant height (cm), **TSL** - Total spike length (cm), **ESL** - Effective spike length (cm), **NS** - Number of spikes, **NC** - Number of capsules, **TW** - Test weight (g), **YPP** - Yield per plant (g)

Table 3: Phenotypic path co-efficient analysis in advanced breeding lines of castor.

Trait	DM	DFF	NN	PH	TSL	ESL	NS	NC	TW	rp YPP
DM	**-0.3141**	0.1759	-0.0124	-0.0163	0.0259	-0.0476	-0.0148	-0.1718	0.0006	**-0.374****
DFF	-0.1902	**0.2905**	-0.1492	-0.0215	0.0133	0.0100	-0.0456	-0.1313	-0.0011	**-0.225**
NN	-0.0119	0.1329	**-0.3260**	0.0407	-0.0334	0.0894	-0.0301	0.1165	0.0002	**-0.021**
PH	0.0373	-0.0455	-0.0964	**0.1378**	-0.0464	0.0985	0.0543	0.2298	-0.0002	**0.369****
TSL	0.0887	-0.0422	-0.1185	0.0696	**-0.0919**	0.2865	0.1287	0.2222	0.0022	**0.545****
ESL	0.0388	0.0075	-0.0757	0.0352	-0.0684	**0.3849**	0.0864	0.0884	0.0034	**0.500****
NS	0.0162	-0.0463	0.0343	0.0261	-0.0413	0.1162	**0.2864**	0.1029	0.0006	**0.495****
NC	0.1339	-0.0946	-0.0942	0.0785	-0.0506	0.0845	0.0731	**0.4030**	-0.0025	**0.531****
TW	-0.0173	-0.0262	-0.0071	-0.0030	-0.0166	0.1077	0.0158	-0.0848	**0.0122**	**-0.019**

Residual= 0.3914; * Significant at 5% (p = 0.05); ****** Significant at 1% (p = 0.01)
DM - Days to maturity, **DFF** - Days to 50% flowering, **NN** - Number of nodes, **PH** - Plant height (cm), **TSL** - Total spike length (cm), **ESL** - Effective spike length (cm), **NS** - Number of spikes, **NC** - Number of capsules, **TW** - Test weight (g), **YPP** - Yield per plant (g)

The relatively stronger genotypic correlations compared with the corresponding phenotypic correlations suggest that the associations among these traits and yield were more strongly governed by genetic factors, with environmental effects contributing to the observed phenotypic relationships. The significant positive association of plant height (Shuaibu *et al.*, 2022), with yield may be attributed to the greater vegetative growth and overall plant architecture associated with taller plants, which can support the development of more reproductive structures, including longer spikes and a greater number of capsules, thereby contributing to higher yield per plant. Similarly, strong positive association of number of spikes, total and effective spike length (Deepak *et al.*, 2024), with yield indicates their close relationship with productivity, possibly because a greater number of spikes and longer total spike length provide more reproductive sites for capsule formation, thereby contributing to higher yield per plant, while the positive association of number of capsules with yield may be attributed to the fact that a greater number of capsules directly provides more sites for seed development and consequently increases the total seed yield per plant.

Conversely, the significant negative association of days to maturity with yield (Dhedhi *et al.*, 2010); Patel *et al.*, (2018a), particularly at the genotypic level, suggests that early-maturing genotypes tended to have higher yield under the conditions evaluated. The negative and non-significant association of number of nodes with yield may be attributed to the fact that a greater number of nodes does not necessarily result in a proportionate increase in productive spikes or capsule-bearing sites. Thus, node number alone may have limited influence on seed yield unless accompanied by effective development of reproductive structures. Likewise, test weight showed a weak negative association with yield per plant (Chaudhari *et al.*, 2019), possibly because higher individual seed weight does not necessarily correspond to a greater number of seeds or capsules per plant; hence, its contribution to overall yield may be limited compared with traits directly contributing to reproductive output. However, correlation alone does not establish a direct causal relationship; therefore, the direct and indirect contributions of these traits to yield were further examined through path coefficient analysis.

Path coefficient analysis

Path coefficient analysis was carried out to partition the correlation coefficients into direct and indirect effects of the component traits on yield per plant. The results revealed considerable variation in the magnitude and direction of direct effects among the traits (Table 3), as illustrated by the path diagram in Fig. 2. Number of capsules recorded the highest positive direct effect on yield (0.4030), followed by effective spike length (0.3849), days to 50% flowering (0.2905) and number of spikes (0.2864). Plant height also exhibited a positive direct effect (0.13780), whereas test weight showed only a

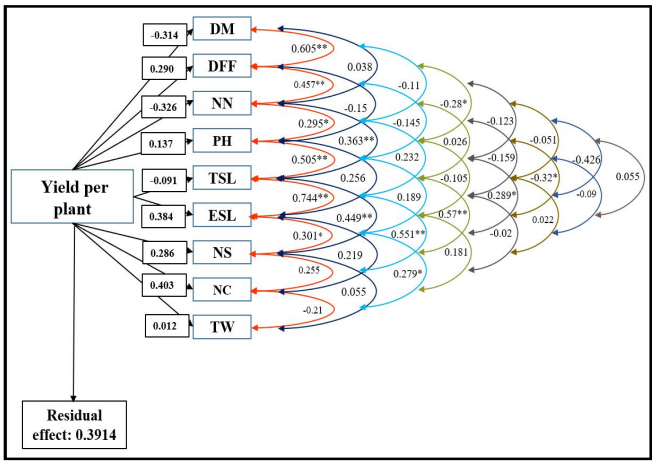


Fig. 2: Phenotypic path co-efficient diagram for yield and its attributing traits.

negligible positive direct effect (0.01223). In contrast, number of nodes showed a high negative direct effect (-0.3260), followed by days to maturity (-0.3141) and total spike length (-0.0919). The residual effect was 0.3914, indicating that the traits included in the path analysis collectively accounted for approximately 60.86% of the variation in yield per plant, while the remaining 39.14% was attributable to other traits and factors not included in the analysis, as well as environmental and random effects.

The positive direct effect of number of capsules on yield (Goodarzi *et al.*, 2015) indicates that capsule number is an important component directly contributing to yield, as a greater number of capsules provides more sites for seed production. The strong positive direct effect of effective spike length (Salihu *et al.*, 2018) suggests that longer effective spikes may provide greater reproductive surface and accommodate more productive structures, thereby contributing directly to yield. Similarly, the positive direct effect of number of spikes indicates that it provides more sites for capsule formation and seed development, thereby contributing directly to higher yield per plant.

The positive correlation of total spike length with yield, despite its negative direct effect (-0.0919), was mainly due to its positive indirect effects through effective spike length (0.2865), number of capsules (0.2222) and number of spikes (0.1287). This indicates that the association of total spike length with yield was largely mediated through other yield-contributing traits rather than through its direct effect. Likewise, the positive correlation of plant height with yield was supported by its positive direct effect (0.1378) and positive indirect effects through number of capsules (0.2298), number of spikes (0.0543) and effective spike length (0.0985).

The significant positive association of effective spike length, number of spikes and number of capsules with yield was supported by their positive direct effects (Alhaji *et al.*, 2019), indicating their potential importance in determining yield. Among these traits, number of capsules and effective spike length exhibited the strongest direct effects, suggesting that their contribution to yield was relatively more direct. The negative association of days to maturity (Golakia *et al.*, 2007) with yield was consistent with its negative direct effect (-0.3141), which was further reinforced by its negative indirect effects through number of capsules (-0.1718) and effective spike length (-0.0476). Number of nodes exhibited a negative direct effect (-0.3260), which contributed to its negative association with yield per plant. Test weight had a negligible positive direct effect (0.0122), indicating that its association with yield was not primarily due to its direct contribution to yield.

Overall, the path analysis indicated that number of capsules, effective spike length and number of spikes were important traits owing to their positive direct effects as well as their positive associations with yield per plant. These traits may therefore be considered important yield-contributing attributes in the evaluated castor advanced breeding lines, while the strong negative direct effects of days to maturity and number of nodes indicate that their relationships with yield require consideration alongside their indirect effects through other traits.

Conclusion

The present study revealed significant genetic variability among the evaluated castor advanced breeding lines for all the traits studied, indicating considerable scope for selection and genetic improvement. Yield per plant exhibited significant positive phenotypic and genotypic associations with plant height, total spike length, effective spike length, number of spikes and number of capsules, whereas days to maturity showed a significant negative association with yield. Path coefficient analysis further revealed that number of capsules, effective spike length and number of spikes had substantial positive direct effects on yield per plant, highlighting their importance as major yield-contributing traits. The strong positive association of these traits with yield, together with their positive direct effects, suggests that they could serve as useful selection criteria for improving yield in castor advanced breeding lines. Overall, the combined correlation and path analysis identified number of capsules, effective spike length and number of spikes as important traits for yield improvement, which may be given greater emphasis in selection programmes involving advanced breeding lines of castor

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