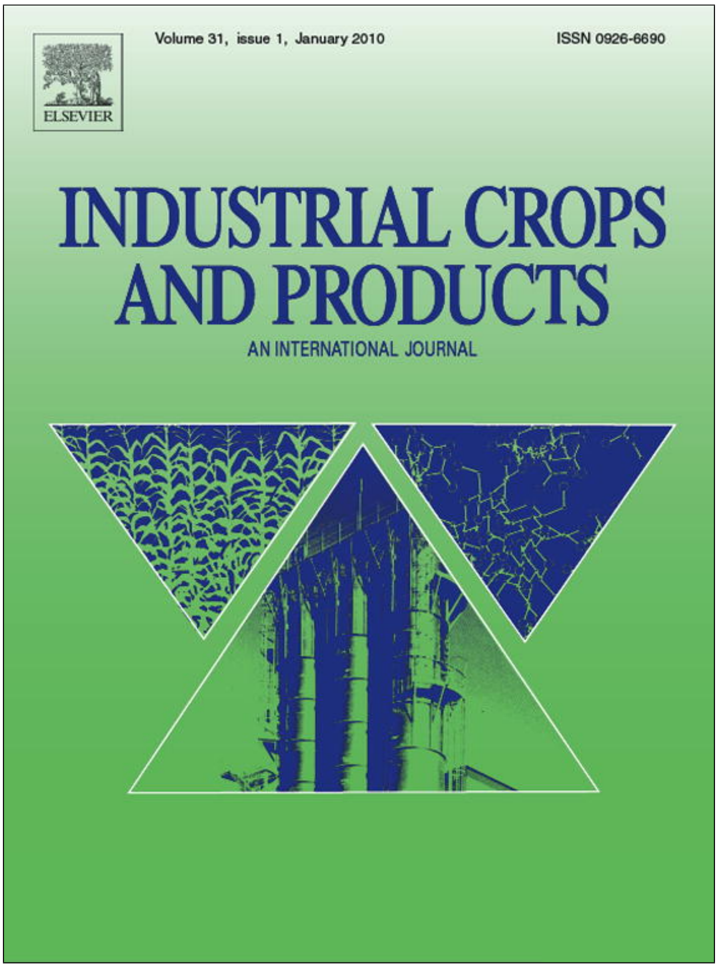
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Extra-early maturing germplasm for utilization in castor improvement

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ABSTRACT

Diverse sources of extra-earliness are required for breeding high yielding extra-early castor (*Ricinus communis* L.) cultivars. Twenty-three extra-early accessions and four checks were evaluated from 2003–2004 to 2007–2008. Variance components for 14 traits and correlation coefficients were estimated. Significant genotypic differences were observed for these traits. Number of main stem nodes, days to 50% flowering and days to maturity exhibited high σ^2_g and non-significant $\sigma^2_{g\times e}$ interactions. They showed significant high positive correlations with each other and very low associations with yield and its components. Yield exhibited moderate associations with its components except 100-seed weight. Cluster analysis grouped the entries into four groups. All 23 accessions exhibited stable performance for extra-early maturity. Accessions were identified for high oil content, high yield and high per day productivity. The promising accessions identified and the information generated would be useful for breeding extra-early cultivars as well to study inheritance of extra-earliness.

1. Introduction

Castor (*Ricinus communis* L.) is an important industrial oilseed crop. Its seed oil has more than 400 industrial uses ranging from medicines to biodiesel production (Devendra and Raghavan, 1978; Bhardwaj et al., 1996). India, Brazil and China are the major castor producing countries. Castor is generally grown as an annual crop even though it is essentially a perennial shrub and indeterminate in fruiting habit. Castor cultivars are classified as early (120–140 days), medium (140–160 days) and late (>160 days) maturity types based on duration taken from planting to maturity of primary raceme (Weiss, 1983; Atsman, 1989). In India, it is mainly grown as a six–eight months duration crop and planting is generally taken up between June and July. Harvesting is done in four pickings from 120 to 210 days after planting with one-month interval between pickings. About 80% of castor production in India comes from rainfed areas (Damodaram and Hegde, 2007). Moisture stress is the major yield limiting factor in castor. The crop generally undergoes moisture stress at around 60–65 days after planting that coincides with flowering and capsule formation stages. Extra-early maturing (<100 days) cultivars would enable the crop to grow and set seeds before moisture stress sets in. They would also reduce production cost and facilitate expansion of the crop to newer areas by fitting into multiple cropping schemes of the areas. In the past, most castor breeding programmes focused primarily on developing high yielding medium duration cultivars. Extra-early maturing cultivars are not yet available. Development of high yielding extra-early cultivars is a challenge as early flowering habit is generally associated with low productivity. Diverse extra-early maturing sources are primarily required for breeding high yielding extra-early cultivars. At the Directorate of Oilseeds Research, Hyderabad, India, 23 extra-early accessions which mature in less than 100 days were developed. Information on genetic divergence of these extra-early accessions, their yield performance and stability for extra-earliness are needed to promote their use in developing high yielding extra-early cultivars.

In the present study, 23 extra-early accessions were evaluated along with four checks of different maturity durations in five contiguous years (2003–2007). Yield performance of 23 extra-early accessions over years and genetic divergence in these accessions were assessed. In addition, G × E interaction, variance components and correlations among 14 quantitative traits were estimated. The information generated should be useful to breeders in selection of appropriate extra-early parental lines and to fine-tune the breeding programmes aimed at development of extra-early cultivars.

2. Material and methods

Twenty-three extra-early accessions along with four checks *viz.*, 'Sowbhagya', '48-1', 'DCS-9' and 'GCH-4' were planted between second and third week of June in 2003, 2004, 2005, 2006 and 2007 in a randomized complete-block design with three replications under rainfed conditions in Alfisol at the Directorate of Oilseeds Research, Hyderabad, India (17.366°N and 78.478°E). The checks used are

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Table 1
Morphological traits and country of origin of parental sources of extra-early accessions and checks.

Accession	Country of origin and identity number of parental sources and checks	Stem colour	Bloom	Capsule size and nature	Capsule dehiscence	Seed size, shape and colour
RG 155	Former USSR (EC154818)	Purple	0	B, SP	NDC	B, E, DRC
RG 211	Former USSR (EC170488-1)	Purple	0	M, SP	PDC	S, E, BR
RG 30	Former USSR (EC170486)	Purple	0	M, SP	NDC	S, O, DRC
RG 148	Former USSR (EC153579)	Green	2	M, SP	NDC	B, E, BR
RG 210	Former USSR (EC170487)	Red	1	M, SP	NDC	S, O, DRC
RG 26	USA (EC169671-1)	Green	0	M, NSP	NDC	S, E, BR
RG 24	USA (EC169662)	Purple	0	S, SP	PDC	S, E, DRC
RG 28	USA (EC169689)	Purple	0	B, SP	PDC	S, E, DRC
RG 190	USA (EC169666)	Green	2	M, NSP	NDC	B, E, BR
RG 25	USA (EC169671)	Green	0	M, SP	NDC	S, O, BR
RG 187	USA (EC169663)	Green	1	B, SP	NDC	S, E, DRC
RG 188	USA (EC169664-1)	Green	1	S, SP	NDC	S, E, BR
RG 18	Hungary (EC168752)	Red	2	S, SP	NDC	S, O, DRC
RG 19	Hungary (EC168752)	Red	1	M, NSP	NDC	S, O, DRC
RG 20	Hungary (EC168752)	Red	1	M, NSP	DC	S, O, DRC
RG 22	Hungary (EC168754)	Red	0	M, NSP	NDC	S, O, DRC
RG 179	Hungary (EC168757)	Purple	0	M, SP	NDC	S, O, DRC
RG 181	Hungary (EC168759)	Red	1	M, SP	PDC	B, E, DRC
RG 17	Hungary (EC168752)	Red	2	S, SP	NDC	S, O, DRC
RG 180	Hungary (EC168758)	Purple	0	B, SP	PDC	S, O, DRC
RG 14	Unknown (EC103746)	Purple	0	S, SP	NDC	S, O, BR
RG 15	Unknown (EC151810)	Purple	0	S, SP	NDC	S, O, BR
RG 125	Unknown (EC103745)	Red	0	M, SP	NDC	S, O, DRC
DCS9 (EC[a])	India	Red	2	M, SP	NDC	M, O, BR
48-1 (MC)	India	Red	2	B, NSP	NDC	M, O, BR
Sowbhagya (LC)	India	Red	2	S, SP	NDC	S, O, BR
GCH 4 (MC)	India	Red	3	B, SP	NDC	M, O, BR

EC[a]: early maturing check; MC: medium maturing check; LC: late maturing check; EC: exotic collection identity number given by National Bureau of Plant Genetic Resources, New Delhi, India; 0: the absence of bloom; 1: the presence of bloom on stem; 2: the presence of bloom on stem and lower surface of leaf; 3: the presence of bloom on stem and lower and upper surface of leaf; B: big; M: medium; S: small; SP: spiny; NSP: non-spiny; NDC: non-dehiscent; PDC: partially dehiscent; DC: dehiscent; E: elongated; O: oval; DRC: dark chocolate; BR: brown.

commercial cultivars with different maturity durations. 'DCS 9' is an early maturing variety, 'Sowbhagya' is a late maturing cultivar and '48-1' and 'GCH 4' are medium maturing variety and hybrid, respectively. The 23 extra-early accessions, which were selected from 43 heterogeneous exotic collections, had under gone seven to eight generations of self-pollination to bring in genetic uniformity especially for the maturity related traits like number of main stem nodes, days to flowering and days to maturity and various morphological traits. Each test entry was planted in two rows, 5 m long, spaced 45 and 90 cm within and between rows, respectively in each replication. Recommended doses of fertilizers and plant protection measures were applied to experiment. Meteorological data were recorded using automatic weather station. The minimum and maximum temperatures varied from 20 to 22 °C and 31 to 34 °C, respectively and the total rainfall was between 609 and 1114 mm during crop period (June to March) during 2003–2004 to 2007–2008.

Data were recorded on 15 random plants in each entry in each replication for 14 quantitative traits *viz.*, plant height (cm), number of main stem nodes up to primary raceme, days to 50% flowering, days to maturity, total number of racemes/plant, total length of primary raceme (cm), primary raceme length covered by capsules (cm), 100-seed weight (g), oil content (%), seed yield at 120, 150, 180 and 210 days after planting (g/plant) and total seed yield (g/plant). Plant height (cm) was measured from ground surface to the base of primary raceme. Days to 50% flowering was measured as number of days taken from planting to flowering of primary racemes in 50% of plants of an entry. Number of days taken from planting to maturity of primary raceme was considered as days to maturity. Number of total productive racemes/plant was counted. Total length of primary raceme (cm) was measured from base to tip of the raceme. The part of primary raceme covered by capsules was measured as primary raceme length covered by capsules (cm). As castor is indeterminate in fruiting, harvesting was done in four pickings at 120, 150, 180 and 210 days after planting (DAP). Combined seed yield of all pickings was taken as total seed yield (g/plant). Seed oil content (%) was measured using NMR equipment. Per day productivity (g/plant) of each entry was calculated by dividing the seed yield (g/plant) of each entry at a particular picking (120, 150, 180 and 210 DAP) by its days to maturity. Cumulative per day productivity (g/plant) of each entry was calculated by dividing total seed yield by days to maturity. Data on 14 quantitative traits were analysed for each year as well as for five years combined using MSTATC software. Mean and range for 14 quantitative traits were computed. The variance components due to genotype (σ^2_g) and error (σ^2_e) were estimated in each year and also the variance component due to genotype × environment ($\sigma^2_{g\times e}$) for five years combined was estimated for 14 quantitative traits. Genotypic correlation coefficients among 14 quantitative traits were estimated for each year separately and also for five years combined. Entire data of all five years were combined to get pooled correlation coefficients. Genetic diversity among the test entries was assessed by cluster analysis using Ward's Minimum Variance. Visual observations of stem colour, bloom (waxy coating), capsule size, nature and dehiscence of capsule, and seed size, shape and colour were recorded for each entry. Capsule which had <1.5 cm diameter was classified as small and that with >3 cm diameter as big, while the one in between was taken as medium size capsule. Seed having <1.5 cm seed index (length × breadth) was considered as small seed while the one having >3 cm seed index was taken as big seed and the intermediate index one was considered as medium seed. Since measuring capsules and seed size is a time and labour consuming process, test entries were visually compared with commercial varieties namely 'Aruna', '48-1' and 'CO-1' for sizes of capsules and seeds. 'Aruna' was taken as a standard genotype for small size capsule (1.4 cm) and seed (1.2 cm) and '48-1' was for medium size capsule (2.5 cm) and seed (1.9 cm), while 'CO-1' was taken as a standard for big size capsule (3.7 cm) and seed (3.4 cm).

3. Results and discussion

Geographic origin of the original exotic collections from which the 23 extra-early accessions were developed, and morphological traits of extra-early accessions are given in Table 1. Parental sources of 20 extra-early accessions represented diverse geographical regions. Origin countries of parental sources of three accessions were not known. Polymorphism was observed among extra-early accessions for stem colour, bloom, capsule size, nature and dehiscence, and seed size, shape and colour. Of the 23 accessions, 17 possessed non-dehiscent capsules while five had partially dehiscent and one had dehiscent capsules. Non-dehiscent and partial dehiscent capsules are desirable types in castor to prevent seed dispersal before harvesting since in these types seeds don't shatter out even after drying of capsules.

3.1. Variance components

Highly significant genotypic variance was revealed for all the traits investigated and non-significant replication variance within year was revealed. Differences due to years was non-significant for number of main stem nodes, days to 50% flowering, days to maturity, 100-seed weight and oil content. Genotype and year (G × E) interaction was highly significant for plant height, total length of primary raceme, primary raceme length covered by capsules, number of total racemes/plant, seed yield at 120, 150, 180 and 210 days after planting and total seed yield implying high influence of environment on these traits. G × E interaction was non-significant for 100-seed weight, oil content, number of main stem nodes, days to 50% flowering and days to maturity (Table 2) indicating negligible influence of environment on these traits. Non-significant G × E interaction for days to 50% flowering and days to maturity and significant interaction for seed yield were reported in castor (Joshi et al., 2002).

Significant genetic variances (σ_g^2) were observed for all quantitative traits suggesting that effective selection for these traits would be possible (Table 2). Preponderance of genetic variance for maturity related traits like number of main stem nodes, days to 50% flowering and days to maturity was reported earlier in castor (Hooks et al., 1971; Dorairaj et al., 1973a; Bhatt and Reddy, 1981; Singh and Yadav, 1981; Patel et al., 1984; Moshkin, 1986; Sarwar and Chaudhry, 2008).

Non-significant genetic and year interaction variances ($\sigma_{g\times e}^2$) were estimated for number of main stem nodes, days to 50% flowering, days to maturity, 100-seed weight and oil content, while significant $\sigma_{g\times e}^2$ were estimated for plant height, total length of primary raceme, primary raceme length covered by capsules, total number of raceme/plant, total seed yield/plant and seed yield/plant at 120, 150, 180 and 210 days after planting (Table 2). High σ_g^2 and very low $\sigma_{g\times e}^2$ estimates for days to 50% flowering and days to maturity suggest that these traits were little affected by environment. Yield and its components, except 100-seed weight exhibited high magnitude of $\sigma_{g\times e}^2$ indicating high influence of environment on them. The presence of larger σ_g^2 than $\sigma_{g\times e}^2$ for all traits, except plant height and total number of racemes/plant, suggests existence of enough genetic control of these traits regardless of environmental effect. These results were in accordance with earlier findings in castor (Giriraj et al., 1973; Dorairaj et al., 1973a; Ramaswamy and Madhavan Menon, 1973; Singh and Yadav, 1981; Swarnalata et al., 1984; Dangaria et al., 1993; Manivel and Hussain, 1997; Sarwar and Chaudhry, 2008).

Table 2
Pooled analysis of variance and variance components due to genotype (σ_g^2) and genotype × year ($\sigma_{g\times e}^2$) for 14 quantitative traits.

	d.f.	Mean squares													
		PH	NN	DF	DM	TLPR	PRCC	TRP	SW	OC	Seed yield at different DAP				Total seed yield
											120	150	180	210	
Years	4	605.7*,**	132.9	137.8	202.4	351.7*,**	259.2*,**	879.6*,**	124.1	704.2	989.3*,**	896.5*,**	1120.4*,**	1257.4*,**	5552.3*,**
Reps within year	10	127.5	11.2	10.24	8.5	214.1	228.4	157.3	18.7	12.5	89.7	101.4	112.4	221.3	132.5
Genotype	26	1125.4*,**	492.9*,**	689.7*,**	859.6*,**	584.7*,**	482.3*,**	477.8*,**	654.7*,**	597.5*,**	4898.7*,**	2527.4*,**	1568.2*,**	1028.1*,**	6524.9*,**
Genotype × year	104	909.2*,**	0.6	8.5	12.2	158.2*,**	159.9*,**	176.2*,**	12.3	8.7	1007.6*,**	1345.2*,**	1757.2*,**	1782.4*,**	1421.5*,**
Pooled error	260	23.1	0.5	7.8	8.2	13.5	8.2	5.6	0.4	0.2	53.4	22.5	13.5	3.8	312.2
σ_g^2		195 (1.52)	17 (0.41)	308 (1.82)	268 (1.11)	69 (1.72)	67 (1.97)	9 (1.24)	18 (0.42)	9 (2.12)	532 (4.71)	584 (5.92)	372 (2.71)	317 (1.64)	4123 (6.78)
$\sigma_{g\times e}^2$		295 (1.6)	0.1 (0.02)	0.2 (0.42)	0.9 (0.8)	48 (1.11)	36 (1.04)	35 (1.03)	3 (0.04)	2 (0.01)	318 (2.43)	440 (1.78)	281 (1.58)	292 (1.94)	1269 (5.28)

PH: plant height; NN: number of main stem nodes; DF: days to 50% flowering; DM: days to maturity; TLRP: total length of primary raceme; PRCC: primary raceme length covered by capsules; TRP: total racemes/plant; SW: 100-seed weight; OC: oil content; DAP: days after planting; figures in parentheses indicate standard error.

* Significant at 0.05 level of probability.

** Significant at 0.01 level of probability.

Table 3
Mean values of 14 quantitative traits in 23 extra-early accessions and four checks combined over five years.

Entries	PH (cm)	NN	DF	DM	TLPR (cm)	PRCC (cm)	TRP	SW (g)	OC (%)	Yield at different days after planting (g/plant)				Total yield (g/plant)	Percent of total yield realized at 120 DAP
										120	150	180	210		
RG 14	27	7	28	89	22	15	11	26	48	46	3	0	0	49	94
RG 15	16	8	34	91	14	9	10	27	46	24	13	8	1	46	52
RG 17	27	7	26	79	14	10	12	20	48	37	27	23	11	98	38
RG 18	28	8	30	84	17	11	15	20	45	66	34	19	3	122	54
RG 19	29	7	30	82	18	12	15	23	47	67	34	25	5	131	51
RG 20	24	8	33	88	20	14	15	26	44	44	21	11	8	84	52
RG 22	25	8	36	90	30	19	14	30	49	53	30	14	5	101	52
RG 24	23	8	32	89	25	21	13	25	48	34	4	0	0	38	89
RG 25	16	8	32	88	12	8	14	27	48	43	22	10	5	80	54
RG 26	22	7	29	89	14	9	13	23	40	73	6	0	0	78	94
RG 28	29	7	31	87	23	13	13	34	48	48	3	0	0	52	92
RG 30	28	8	33	91	21	14	14	24	37	59	28	20	15	122	48
RG 125	33	7	27	82	15	11	14	26	46	37	24	13	5	79	47
RG 148	46	8	34	92	22	15	15	25	47	38	20	0	0	57	67
RG 155	23	6	27	80	12	10	13	25	50	20	8	1	0	29	69
RG 179	37	8	33	89	25	16	12	28	47	73	45	0	0	118	62
RG 180	24	6	28	81	17	12	13	29	50	24	11	2	2	39	62
RG 181	50	8	32	90	18	10	12	28	50	33	16	6	2	57	58
RG 187	47	8	33	88	25	13	14	28	49	27	12	6	0	45	60
RG 188	50	8	34	91	19	10	13	29	47	25	15	5	0	45	56
RG 190	36	8	34	91	26	17	14	29	51	22	9	3	1	34	65
RG 210	36	8	36	90	47	33	15	37	49	85	64	36	16	201	42
RG 211	32	7	32	91	20	12	11	33	49	25	3	0	0	28	89
'DCS 9' (EC)	57	16	72	126	37	32	18	27	48	86	71	40	5	202	42
'48-1' (MC)	90	20	85	145	40	35	18	31	48	25	72	70	38	205	12
'GCH 4' (MC)	80	18	81	142	37	34	17	30	49	60	86	68	46	260	23
'Sowbhagya' (LC)	56	26	120	170	19	14	12	17	48	0	7	55	58	120	0
CV (%)	13	8	7	3	16	18	17	2.6	1	17	19	23	24	19	
CD (P = 0.05)	7	1	4	4	7	6	2	1	0.7	16	11	8	4	30	

EC: early maturing check; MC: medium maturing check; C: late maturing check; PH: plant height; NN: number of main stem nodes; DF: days to 50% flowering; DM: days to maturity; TLRP: total length of primary raceme; PRCC: primary raceme length covered by capsules; TRP: total racemes/plant; SW: 100-seed weight; OC: oil content; DAP: days after planting.

3.2. Performance of extra-early accessions

The multi-year evaluation revealed wide differences between extra-early accessions and checks with respect to phenology and yield performance. Stable performance of extra-early accessions over years for number of main stem nodes, days to 50% flowering, days to maturity, 100-seed weight and oil content was observed, while for other traits year to year variations were detected. The stable performance of extra-early accessions for maturity related traits is very promising for their reliable exploitation in castor improvement for extra-earliness. Extra-early accessions on an average flowered 41 days earlier and matured 39 days earlier than the early maturing check 'DCS 9'. Five years combined mean values of 14 quantitative traits of 23 extra-early accessions and four checks are given in Table 3. Number of main stem nodes ranged from six to eight among extra-early accessions while it was between 16 and 26 among checks. There were great differences between extra-early accessions and checks for days to 50% flowering and days to maturity. Days to flowering ranged from 26 to 36 days among extra-early accessions while it was 72–120 days among checks. Among extra-early accessions, days to maturity ranged from 79 to 92 days whereas it was from 126 to 170 days among checks. The accession, RG 17 was the earliest maturing entry which reached to 50% flowering in 26 days and matured in 79 days. Four accessions *viz.*, RG 155, RG 180, RG 19 and RG 125 also matured very early (80–82 days). Four accessions *viz.*, RG 180, RG 155, RG 181 and RG 190 possessed significantly (P = 0.05) high oil content (50–51%). Great variation was observed among extra-early accessions for total seed yield which ranged from 28 to 201 g/plant. The percent of total seed yield realized at first picking (120 DAP) among extra-early acces-

Table 4
Genotypic correlations among 14 quantitative traits in extra-early accessions pooled over five years.

Trait	NN	DF	DM	TLPR	PRCC	TRP	SW	OC	Yield at different days after planting				Total yield
									120	150	180	210	
PH	0.58*,**	0.65*,*	0.53*,**	0.35*,**	0.18**	−0.21**	0.23*,**	0.22*,**	−0.02	−0.04	−0.06	−0.10	−0.02
NN		0.97*,**	0.92*,**	0.19**	0.14	0.18**	0.15	−0.14	0.29*,**	0.23*,**	0.23*,**	0.25*,**	0.25*,**
DF			0.89*,**	0.19**	0.13	0.25*,**	0.14	−0.12	0.30*,**	0.23*,**	0.24*,**	0.33*,**	0.27*,**
DM				0.24*,**	0.14	0.23*,**	0.14	−0.13	0.27*,**	0.30*,**	0.25*,**	0.34*,**	0.29*,**
TLPR					0.92*,**	0.45*,**	0.67*,**	0.09	0.69*,**	0.65*,**	0.54*,**	0.53*,**	0.62*,**
PRCC						0.47*,**	0.69*,**	0.10	0.70*,**	0.65*,**	0.54*,**	0.58*,**	0.61*,**
TRP							−0.19**	−0.11	0.62*,**	0.61*,**	0.61*,**	0.65*,**	0.62*,**
SW								0.44*,**	0.07	0.06	0.06	0.07	0.06
OC									−0.26*,**	−0.27*,**	−0.28*,**	−0.27*,**	−0.27*,**

PH: plant height; NN: number of main stem nodes; DF: days to 50% flowering; DM: days to maturity; TLPR: total length of primary raceme; PRCC: primary raceme length covered by capsules; TRP: total racemes/plant; SW: 100-seed weight; OC: oil content. Data pooled over five years were used for estimating pooled correlation coefficients.

* Significant at 0.05 level of probability.

** Significant at 0.01 level of probability.

Table 5
Mean and range of 14 quantitative traits in different clusters and composition of different clusters.

Trait	Cluster-I	Cluster-II	Cluster-III	Cluster-IV
Plant height (cm)	25 (16–33)	35 (23–50)	40 (29–57)	75 (56–90)
Number of main stem nodes	8 (7–8)	7 (6–8)	10 (7–16)	21 (18–26)
Days to 50% flowering	30 (26–34)	32 (27–36)	43 (31–72)	95 (81–120)
Days to maturity	86 (79–91)	88 (80–92)	98 (87–126)	152 (142–170)
Total length of primary raceme (cm)	16 (12–21)	21 (12–30)	33 (23–47)	32 (19–40)
Primary raceme length covered by capsules (cm)	11 (8–14)	14 (10–21)	24 (13–33)	28 (14–35)
Total racemes/plant	14 (10–15)	13 (11–15)	15 (12–18)	16 (12–18)
100-seed weight (g)	24 (20–27)	28 (25–33)	32 (27–37)	26 (17–31)
Oil content (%)	45 (37–48)	49 (47–51)	48 (47–49)	48 (48–49)
Seed yield at 120 DAP (g/plant)	50 (24–73)	32 (20–53)	73 (48–86)	28 (0–60)
Seed yield at 150 DAP (g/plant)	23 (6–34)	12 (3–30)	46 (3–71)	55 (7–86)
Seed yield at 180 DAP (g/plant)	14 (0–25)	3 (0–14)	19 (0–40)	64 (55–70)
Seed yield at 210 DAP (g/plant)	6 (0–15)	1 (0–5)	5 (0–16)	47 (38–58)
Total seed yield (g/plant)	93 (46–131)	69 (28–101)	143 (52–202)	195 (120–260)
Entries	RG15, RG17, RG18, RG19, RG20, RG25, RG26, RG30, RG125	RG14, RG22, RG24, RG148, RG 155, RG180, RG181, RG187, RG188, RG190, RG211	RG28, RG179, RG210, 'DCS9'	'Sowbhagya', '48-1' 'GCH 4'

Figures in parentheses indicate the range for the corresponding trait. DAP: days after planting. Data pooled over five years were used for clustering analysis.

sions varied between 38% and 94% indicating existence of great diversity among these accessions for early yield potentiality.

Five accessions *viz.*, RG 14, RG 24, RG 26, RG 28 and RG 211 had all most ceased to yield after first picking as they reached senescence and died before reaching the second picking (150 DAP) stage. The accession, RG 210 is a promising high yielding extra-early accession as it was at par with the early check variety 'DCS 9' with respect to total seed yield and seed yield at different days after planting. RG 210 matured on an average 36 days earlier than 'DCS 9'. The percent of total seed yield realized at 120 DAP from it was parallel to that of 'DCS 9' (42%). There was no yield penalty in RG 210 due to earliness and could yield high even after 120 DAP akin to 'DCS 9'.

RG 210 exhibited the highest cumulative per day productivity (2.23 g/plant) as well as per day productivity at 120 DAP (0.68 g/plan), 150 DAP (0.71 g/plant), 180 DAP (0.4 g/plant) and 210 DAP (0.18 g/pant). The accessions *viz.*, RG 18 (0.79 g/plant), RG 19 (0.82 g/plant), RG 26 (0.82 g/plant) and RG 179 (0.82 g/plant) had significantly higher per day productivity than the checks at 120 DAP. These accessions can be exploited for extra-earliness together with ability for high per day productivity.

3.3. Correlations

Genotypic correlation coefficients were calculated every year for 14 quantitative traits in extra-early accessions to understand the association patterns among these traits. Consistent trends in associations among traits were observed over years. Genotypic correlations pooled over five years for 14 quantitative traits are presented in Table 4. Very high significant positive associations were observed among number of main stem nodes, days to 50% flowering and days to maturity. These traits exhibited significant moderate positive correlation with plant height, low positive associations with total length of primary raceme, number of racemes/plant, seed yield at 120, 150, 180 and 210 DAP, total seed yield, and non-significant associations with primary raceme length covered by capsules and 100-seed weight. These findings were in accordance with earlier reports in castor (Bhatt and Reddy, 1981; Mehta and Vashil, 1998). Positive associations among main stem nodes, days to flowering and days to maturity were reported in other crops also (Bourland et al., 2001; Rauf et al., 2005). Number of main stem nodes is generally considered as an indicator to assess days to 50% flowering and days to maturity in castor (Weiss, 1983). The same was supported by the high positive correlation of number of main stem nodes with days to 50% flowering and days to maturity in the present study. Similar relation was reported in cotton where node number of first-position white flower relative to the apex was considered as maturity indicator (Waddel, 1974). The low associations of maturity traits with seed yield suggest that selection for earliness not necessarily would incur yield penalty. Similar results were also demonstrated in early maturing cultivars of *Brassica napus* (Degenhart and Kondra, 1984), cotton (Bednarz and Nichols, 2005), oats (Ahmed et al., 2008) and peanut (Perera et al., 2004; Upadhyaya et al., 2005).

Total seed yield and seed yield at 120, 150, 180 and 210 DAP exhibited significant positive moderate associations with yield traits like total length of primary raceme, primary raceme length covered by capsules and total number of racemes/plant. Total seed yield and seed yields at different harvestings showed extremely low non-significant associations with 100-seed weight. However, seed weight had significant moderately high positive association with yield traits like total length of primary raceme and primary raceme length covered by capsules and significant low negative association with total number of racemes/plant. The associations among yield traits and their correlations with seed yield suggest that simultaneous improvement of castor for extra-earliness and seed yield would be possible. Earlier studies in castor also revealed positive association of seed yield with total length of primary raceme, total number of racemes/plant and 100-seed weight (Dorairaj et al., 1973b; Yadav and Singh, 1973; Salih and Khidir, 1975; Moshkin, 1986; Sarwar and Chaudhry, 2008).

Oil content showed non-significant negative association with maturity related traits, significant low positive correlation with plant height, and non-significant very low positive association with total length of primary raceme, primary raceme length covered by capsules and number of total racemes/plant. Significant positive moderate association was observed between oil content and 100-seed weight. Positive association between seed weight and oil content was also reported by Salih and Khidir (1975) in castor. Non-significant associations between oil content and maturity related traits are encouraging to select extra-early maturing genotypes without effecting oil content. The present study revealed that the associations among various traits in extra-early castor did not differ from those reported earlier using non-extra-early castor.

3.4. Genetic diversity

Knowledge on extent of genetic diversity in the breeding material is essential to select diverse parental lines for hybridization programmes in order to obtain novel and enhanced variability for desirable traits. Genetic diversity studies based on quantitative traits was taken up in many crops including castor (Neto et al., 2004; Costa et al., 2006; Wang et al., 2007). Diversity analysis grouped 23 extra-early accessions and four checks into four clusters. Geographical origin of original sources of extra-early accessions had played no role in their clustering. This reflects that the variation acquired by the extra-early accessions was independent of their geographic origin. Allan et al. (2008) also reported that geographic distribution of 41 castor accessions collected across continents or countries within continents had no role in their grouping.

Twenty-three extra-early accessions and 'DCS 9'were grouped into first three clusters while the medium ('48-1' and 'GCH 4') and late maturing ('Sowbhagya') checks were grouped into the fourth cluster. Cluster-I included nine accessions, cluster-II had 11 accessions and cluster-III comprised three extra-early accessions and the early check 'DCS 9' while cluster-IV comprised three checks (Table 5). Cluster-I and II were comparable for mean values of maturity related traits whereas cluster-III deviated slightly from these clusters because of inclusion of 'DCS 9' in it. Cluster-IV varied significantly from other clusters with respect to all traits as it included only medium and late maturing checks. The four high oil accessions (RG 180, RG 181, RG 155 and RG 190) were placed in cluster-II. Distribution of 23 accessions into three diverse clusters is indicative of the presence of considerable diversity among these accessions. This indicates that generation of additional variability would be possible by inter crossing the accessions from different clusters.

4. Conclusions

The information generated would be useful to breeders in selection of appropriate high yielding extra-early parental lines and to fine-tune the breeding programmes aimed at development of extra-early cultivars. Genetic diversity existing among 23 extra-early accessions is encouraging to create variability for desirable traits by intercrossing them. The accession, RG 210 is a promising high yielding extra-early genotype which is worth testing at multilocations for variety release proposal. The accessions *viz.*, RG155, RG 180, RG 181 and RG 190 can serve as parental lines for extra-earliness coupled with high oil content in crossing programmes. For high per day productivity at 120 DAP coupled with extra-earliness, the accessions *viz.*, RG 18, RG 19, RG 26 and RG 179 are the ideal sources. RG 17 is the best genotype for studying inheritance of extra-earliness and to develop molecular markers linked to extra-earliness. The accessions, RG 14, RG 24, RG 26, RG 28 and RG 211 may be useful for studying basic physiological aspects pertaining to early senescence and death in castor.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.indcrop.2009.09.016.

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