Standardization of procedure for assessing terminal drought stress tolerance induced by foliar spraying of potassium iodide and identification of promising castor germplasm using the developed procedure

P LAKSHMAMMA, LAKSHMI PRAYAGA, K ALIVELU AND A VISHNUVARDHAN REDDY

ICAR-Indian Institute of Oilseeds Research, Rajendranagar, Hyderabad-500 030, Telangana

(Received: February 13, 2019; Revised: March 18, 2019; Accepted: March 20, 2019)

ABSTRACT

Castor cultivated as a rainfed crop in southern India experiences terminal drought stress with cessation of monsoon. Stem reserves act as an important source of carbon for the seeds getting filled when photosynthesis is inhibited by drought and therefore, the ability to mobilize stem reserves towards economic yield is an important trait in selection for terminal drought tolerance. Potassium iodide (KI), a chemical contact canopy desiccant induces leaf desiccation by reducing chlorophyll content and can be used to simulate the conditions of terminal drought stress. This property could be employed for assessing the genotypic variability for stem reserve mobilization trait. During *kharif* 2015-16, in RG 1826, a genotype that had been identified earlier for root and drought tolerance, KI was sprayed @ 0.2-1.0% at 50% filling of capsules on primary spikes or 1.0-3.0% at 50% filling of capsules on tertiary spikes separately as two sets of foliar sprays. KI spray @1.0% at both the stages recorded total leaf desiccation, less seed yield reduction in primary (16%) and tertiary (29%) order spikes. Hence, 1.0% KI was taken as the optimum concentration to screen castor genotypes for terminal drought stress tolerance. During late *rabi* 2016-17, 12 germplasm lines with known drought tolerance (moisture stress induced between 30 and 90 DAS) ability and better root growth characters along with two checks were sown and at 100 DAS, KI was sprayed @ 1.0%. Four genotypes, *viz.,* RG82, RG89, RG111, RG1437 with high stem reserve mobilization characterized by <30% reduction in total seed yield and <20% reduction in HI were identified as promising for terminal drought tolerance.

Keywords: Castor, Genotypic variability, Potassium iodide, Terminal drought stress

Stem reserves are an important source of carbon for grain filling when the current photosynthesis is inhibited by drought or high temperature. The genetic improvement of stem reserve storage and utilization is very important genetic mechanism (Blum, 1998) especially for terminal drought tolerance. If current photosynthesis is limited by environmental stress such as water deficit, then remobilization of previously accumulated assimilates is accelerated. Accumulated assimilates also enhance the recovery of plants after stress (Wardlaw and Eckhardt, 1987). Wide variability exists among genotypes for carbohydrate accumulation in the stems and subsequent organs. Desiccation tolerance is an important physiological mechanism for drought tolerance (Blum, 1983). Chemical desiccation of the canopy after flowering for inhibiting the current photosynthesis was developed as a tool for revealing genotypic differences in grain filling from stem reserves in the absence of current photosynthesis (Blum *et al*., 1983; 1983a). Potassium iodide (KI), a chemical contact canopy desiccant which induce leaf desiccation by reducing chlorophyll content is used to induce drought stress for assessing genetic diversity in stem reserve mobilization to sink (Tyagi *et al*., 2000).

Castor is cultivated as a rainfed crop in southern India and experiences terminal drought stress with cessation of monsoon. Selection of breeding and germplasm lines with terminal drought stress tolerance is needed to develop hybrids that can tolerate end season drought. Hence, experiments were conducted for two years between 2015 and 2017 with the dual objectives of standardization of potassium iodide (KI) concentration to induce terminal drought stress in castor and identification of germplasm lines for terminal drought stress tolerance by imposing KI induced desiccation stress.

MATERIALS AND METHODS

Standardization of potassium iodide (KI) concentration to induce terminal drought stress in castor: The experiment, in two sets, was carried out during *kharif,* 2015-16 at Narkhoda farm of IIOR (located at an altitude of 542 m with latitude of 17° 15' 16" and longitude of 78° 18' 30") using a previously identified drought tolerant germplasm line RG 1826 (Lakshmamma *et al*., 2010, Lakshmamma, 2014). In the Ist set, KI was sprayed @ 0.2, 0.4, 0.5, 0.6, 0.8, and 1.0% at 50% filling of primary spike to select the concentration of KI that induces desiccation. Simple water spray and no-spray treatments acted as checks. Though there was desiccation in 1st set, crop recovered partially due to intermittent small showers. So concentration was increased in 2nd set. In set II, KI was sprayed @ 1.0, 1.5, 2.0, 2.5 and 3.0% at 50% filling of tertiary spikes and water spray as well as no-spray acted as control treatments. Five rows of plants taken with a spacing of 90 x 60 cm, were

---

Corresponding author: p.lakshmamma@icar.gov.in

sprayed with each of the treatment regimen. Data on stem dry weight of different order branches and total dry matter (TDM) was recorded 20 days after spraying as well as at harvest in both the sets of experiments. Seed yield, yield components of different order branches were recorded on 15 plants for each treatment. Partitioning coefficient was calculated for each treatment to assess stem reserve mobilization (Krishnamurthy *et al*., 2013). For measuring partitioning coefficient (p), vegetative and reproductive growth duration converted to thermal time (Cd), crop growth rate (C) and seed yield (Y) were needed and to arrive at these values following formulae were employed

Cd [thermal time]= $\sum^{n}_{t=o}[(t_{max.}+t_{min.})/2-t_{b})]$

where t_{max} is mean maximum temperature during the growth, t_{min} is mean minimum temperature during the growth and t_b is the base temperature.

Base temperature for growth was taken as 19°C for castor as calculated based on the data recorded in different experiments during different seasons along with temperature data with the help of a statistician (data not presented).

C [crop growth rate (kg/ha.)]=(V+Y)/(Dv+Dr)

where, V-vegetative shoot mass (with fallen leaf) kg/ha, Y-grain mass (kg/ha.), Dv-duration of growth before the start of 50% filling of spikes (days), Dr-duration of growth after the start of 50% filling of capsules (days)

p (partitioning coefficient) =((Y/Dr)/C))

where, Y-grain mass (kg/ha), Dr-duration of growth after the start of 50% filling of capsules (thermal time), C-crop growth rate (kg/ha)

Identification of germplasm lines for terminal drought stress tolerance by imposing KI induced desiccation stress: After standardizing the concentration of KI, during late *rabi,* 2016-17, 12 germplasm lines *viz.,* RG 27, RG 72, RG 82, RG 89, RG 111, RG 298, RG 1437, RG 1494, RG 1826, RG 1941, RG 2139, RG 2797 along with two checks; 48-1, a variety, DCH-519, a hybrid with known drought tolerance (of stress between 30 and 90 DAS) selected during different years were sown in un-replicated trial with six rows at a spacing of 90 x 30 cm per treatment and screened for terminal drought stress tolerance by spraying 1% KI (identified as the ideal concentration for inducing terminal stress from both sets of experiments) at 100 DAS.

Data on stem weight and TDM at 20 days after spraying, at harvest and seed yield were recorded. HI was derived from the data on TDM and seed yield (Lakshmamma *et al*., 2017). Partitioning coefficient (p) could not be calculated as there were differences in duration of the studied genotypes and the genotypes were at different stages when terminal drought stress was imposed. 'T' test was done to see the significance among control and KI treatments.

RESULTS AND DISCUSSION

End season drought due to monsoon cessation is very common in medium and long duration castor cultivars. Selection of germplasm and breeding lines for terminal drought tolerance is needed to breed for tolerance to end season drought. Castor crop has very strong stem and stem is the major contributor to total dry matter (TDM). Genotypes with stem reserve mobilization are needed to produce under abiotic stress conditions. Due to heavy foliage and limited translocation to reproductive parts when current photosynthesis is inhibited, it results in very low HI values (≤30%) in castor. Selection for best yields often ensures indirect selection for HI. But the increase in HI should not be due to reduced reproductive duration (Krishnamurthy *et al*., 2013). Breeding for increased HI is essential for the development of varieties/hybrids with higher seed and oil yield. One of the options to increase HI is to increase stem reserve mobilization. But how much to be translocated needs to be known considering that any change made to a plant trait has potential trade-offs that needs to be found out and quantified (Denison, 2009).

Partitioning of produced biomass towards the harvested product is one of the key processes to improve WUE (Condon *et al.,* 2004). Selection for the trait 'Partitioning coefficient (p)' improves drought tolerance and yield stability. This trait possesses the best heritability surpassing the estimates for the phonological durations. Selection for this trait is easy and includes a large number of morphological and physiological contributing traits. Harvest Index (HI) is an integration of two negatively linked traits i.e reproductive duration and rate of partitioning (Krishnamurthy *et al*., 1999). Since there is a ceiling to the reproductive growth duration due to ever increasing heat and drought stress at the final stages of reproductive growth, it would be worth aiming to increase p thereby allowing the plants to escape later stress stages without compromising yield formation. Increasing the p is essential to compensate the stress induced yield gaps (Anbessa *et al*., 2007).

As castor is grown mainly as a rainfed crop in Southern India, the crop is expected to experience moisture stress at different stages of phenology depending on the rainfall distribution. Therefore, it is an important objective of breeding experiments to identify genotypes that can mitigate the effects of moisture stress through different mechanisms. Mobilizing the stored reserves from stem under drought conditions is considered to be one such mechanism. We report here, a procedure developed to induce terminal drought at different stages of plant growth by spraying KI, a leaf desiccant and then study the ability of the genotypes to mobilize the stored reserve from stem. Initially, to identify the concentration of KI that induces terminal drought in castor, KI at different concentrations was sprayed at two stages of development on a test genotype RG 1826. This genotype had been identified as a drought tolerant one in our earlier experiments and therefore, we logically went about establishing a procedure for inducing terminal drought using KI and then using that procedure, screened a set of genotypes that had been identified for moisture stress tolerance.

Establishing the procedure for inducing terminal drought using KI

KI foliar sprayed at 50% filling of primary spikes: In this set of experiment, KI was sprayed @ 0.2, 0.4, 0.5, 0.6, 0.8 and 1% concentrations when the crop was at 50% filling of primary spike. Primary and tertiary stem weight did not show much reduction when measured 20 days after spraying, but stem weight of secondary branches showed reduction (11.3, 18.5 g/pl, respectively against 32.1 g/plant in unsprayed control) at 0.8 and 1.0% of KI. Reduction in total stem weight was more in 0.6, 0.8, 1.0% KI spray. Reduction in total dry matter was more at 1.0% KI spray at 20 days after spraying which could also be because of the reduced spike weight (Table 1). However, significant reduction in total stem weight showed that the stem reserves had been mobilized from secondary branches.

On primary and tertiary spikes, not much difference in spike characters *viz*., spike length, effective spike length (ESL) and capsule number was seen with any spray concentration (data not shown) except for reduction in primary seed yield with 1.0% KI (20.5 g compared to 24.3g in control) (Table 2). Reduced stem dry weight of secondaries at 0.8, 1.0% KI spray (Table 1) indicated translocation of stem reserves from secondary branches to primary spike. This was accompanied with reduced spike length, effective spike length (ESL), capsule number, and seed weight of secondaries (Table 2). These observations further indicated that even though the plant tried to mobilize the stem reserve from secondary branches and compensate for photosynthates, the seed yield of primaries was reduced.

KI foliar sprayed at 50% filling of tertiary spikes: Based on the results observed with KI when sprayed at 50% of primary spike filling which showed not much of stem reserve mobilization at less than 1% concentration, KI was sprayed @ 1.0% to 3.0% concentrations at 50% filling of tertiary spikes i.e. at 86 DAS, Crop completed the life cycle within 20 days of spraying with KI. Leaf dry weight reduced with increase in KI concentration (Table 3). With KI spray, no clear difference in stem reserve mobilization was observed from primary, secondary, tertiary branches as well as not much of variation was seen for total stem weight and TDM (Table 3).

Primary seed yield was not influenced by KI spray as the spike had almost matured by that time (Table 4). Though, secondary spike characters did not show reduction up to 2.0%, seed weight reduced with 2.5, 3.0% KI spray due to reduction in capsule number and test weight. Tertiary spike length and capsule number was not influenced by KI spray. But spike weight and seed yield per plant were reduced significantly and the magnitude was high with concentrations beyond 1.0%. Compared to other treatments, the tertiary seed yield reduction was less at 1.0% KI spray (Table 4). Total seed yield was reduced with KI spray at all the concentrations tested (Table 4). Plaut *et al.*, 2004 also reported reduction in duration and rate of grain filling thereby reduced kernel weight due to drought stress at anthesis stage accompanied by high temperature. In rice also, it was reported that early senescence induced by a moderate water deficit during grain filling period could enhance the remobilization of stored assimilates and accelerate the grain filling of rice (Yang *et al.*, 2001).

Table 1 Total stem weight and TDM at 20 days after spraying of KI at 50% filling of primaries

KI concentration (%)	Total stem weight (g/plant)	Spike weight (g/plant)	TDM (g/plant)
0.2	90.6	49.4	156.7
0.4	82.0	44.0	145.5
0.5	83.1	52.0	155.1
0.6	66.5	68.0	150.9
0.8	68.9	46.4	129.5
1.0	63.9	13.0	92.4
Water spray	75.2	39.0	126.4
Unsprayed	93.2	57.0	175.4

Table 2 Spike characters with KI spray at 50% filling of primary spikes

KI concentration (%)	Primary seed weight (g/plant)	Secondary spike characters			Tertiary seed weight (g/plant)	Total seed weight at harvest (g/plant)
		ESL/spike (cm)	Capsule No./spike	Seed weight (g/plant)		
0.2	22.5	24.5	27	39.7	27.6	89.7
0.4	21.8	21.9	20	39.7	34.1	95.5
0.5	25.1	21	19	34.2	32.7	89.0
0.6	22.7	21.9	20	38.6	30.1	91.4
0.8	23.4	17.2	17	33.9	34.0	91.3
1.0	20.5	17.7	14	31.6	25.3	77.4
water spray	24.1	24.5	28	42.8	22.6	89.5
unsprayed	24.3	22.5	22	50.4	22.1	96.7

Table 3 Total leaf, stem weight at 20 days after spraying of KI at 50% filling of tertiary spikes

KI concentration (%)	Leaf dry weight (g/plant)	Total stem weight (g/plant)	TDM (g/plant)
1.0	10.6	86.3	142.9
1.5	4.5	87.9	152.8
2.0	3.3	104.0	187.3
2.5	2.1	94.9	177.0
3.0	5.5	86.5	148.0
water spray	15.2	76.0	146.5
unsprayed	16.8	89.1	169.9

Table 4 Seed yield of different order spikes with KI spray at 50% filling of tertiary spikes

KI Concentration (%)	Primary seed weight (g)	Secondary seed weight (g)	Tertiary seed weight (g)	Total seed weight at harvest (g/plant)
1.0	20.7	40.8	22.4	83.9
1.5	20.4	43.9	12.4	76.7
2.0	27.6	46.9	11.2	85.7
2.5	26.9	35.8	7.4	70.1
3.0	29.4	35.3	9.9	74.5
water spray	20.1	50.5	30.1	100.6
unsprayed	28.6	50.4	31.3	110.3

As stem reserve mobilization induced by KI spray was not clearly demonstrated by the weight measurements, partitioning coefficient (p) was calculated for different concentrations and stages of spray (Table 5). When Potassium iodide (KI) was sprayed @ 0.2-1.0% at 50% filling of primary spikes, leaf desiccation, primary seed yield reduction (16%) and partitioning coefficient (p-0.50) was more in 1.0% KI concentration. with KI spray @1.0-3.0% at 50% filling of tertiary spikes, beyond 1.0% spray tertiary seed yield reduction was very high (>60%) and at 1.0%, tertiary seed yield reduction was less (<29%) and "p" was also high (0.37) compared to other concentrations. Partitioning coefficient (p - 0.33) for total seed yield was also more in 1.0% KI sprayed at 50% filling of tertiary spikes (Table 5). Strong negative relation of partitioning coefficient with percent reduction in tertiary seed yield (R^2=0.99) and total seed yield (R^2=0.57) was observed (Fig 1a & 1b). Significant correlation of grain yield with assimilate translocation rate (ATR) (R^2=0.54) was also reported in rice indicating reduction in current assimilation during reproductive stage under different KI treatments and tolerant genotypes induced an increase in stem reserve mobilization (Singh *et al.*, 2012).

Therefore, based on the observations from the two sets of experiments with KI sprayed at different concentrations at two different phonological stages, KI @1.0% was considered as optimum for screening genotypes of castor for terminal drought stress tolerance.

Identification of castor germplasm lines for terminal drought stress tolerance by imposing KI induced desiccation stress

Twelve germplasm lines *viz*., RG 27, RG 72, RG 82, RG 89, RG 111, RG 298, RG 1437, RG 1494, RG 1826, RG 1941, RG 2139, RG 2797 along with two checks; 48-1, a variety, DCH-519, a hybrid with known drought tolerance (of stress between 30 and 90 DAS) selected during different years were grown during late *rabi*, 2016 and at 100 DAS, one bed was sprayed with KI @ 1.0% to induce terminal drought stress and 2nd bed without spraying was treated as control. When KI was sprayed, RG72, RG89, RG298, RG1437, RG1494, RG1826, RG2139 were at primary seed filling, secondary capsule formation, and tertiary spike formation stage and RG27, RG82, RG111, RG1941, RG2797 were at primary spike formation/expansion, secondary branch production stage.

Except tertiary (46.2%), reduction in stem dry weight of primary, secondary branches and total stem dry weight reduction at 20 days after KI spray was negligible. Reduction in leaf dry weight especially of secondaries and tertiaries was more with an average of 20.8% reduction in total leaf weight with KI spray as there was leaf desiccation and fall. More than 79% leaf fall was noticed in tertiary order branches (Data not shown). Spike dry weight was reduced by 21.6% while TDM was reduced by 15.7% with KI spray (Table 6). Before spraying, RG72, RG 298, RG 1826 produced tertiary branches but only RG 1826 recorded substantial spike weight reduction. Twenty days after spraying, tertiary stem weight was reduced only in RG 72, RG 89, RG 298, RG 1437, RG 1826 compared to the unsprayed control. Among different genotypes studied, >20% reduction in primary stem weight was seen in RG 72, RG111, RG298, RG1437, RG1941 at 20 days after KI spray. RG27, RG72, RG111, RG298, RG1494 showed >30% reduction in stem dry weight of secondary branches (Data not shown). TDM reduction 20 days after spray was less (<30%) and non significant in RG82, RG89, RG1437, RG 1494, RG 1826, RG 1941, RG 2139 while in RG27, RG 82, RG 89, RG111, RG1941, RG 1494 TDM reduction was significant and <25% at harvest (Table 7).

Stem dry weight at harvest showed no change in primary but exhibited more reduction in secondary (21%) and tertiary branches (77%) with KI spray. Overall, there was 24% reduction in stem dry weight with KI spray (Table 6) and the reduction was significant (p-<0.05). Total stem weight of RG72, RG111, RG298 showed >30% reduction at 20 days after spraying but was not significant (Data not shown). Genotypes that showed >30% reduction in stem dry weight at harvest included RG72, RG1437, RG1826, RG1941, and RG2797 (Table 7). Leaf weight reduction was negligible as there was leaf fall with KI spray. TDM reduction was substantial (up to 32%) due to KI spray.

Primary seed yield reduced by 28%, secondary by 47% and no seed yield was seen in tertiaries (Table 6). There was 32% reduction in total seed yield. Reduction in HI was up to 2% with KI spray (Table 8). Among different genotypes, there was <30% reduction in primary seed yield in RG82, RG89, RG1437, RG1941, RG2139. Genotypes RG72, RG89, RG111, RG298, RG1494, RG1826 recorded <35% reduction in secondary seed yield (Data not shown). There was significant difference in total seed yield with KI spray in the studied genotypes. Total seed yield reduction was less (<30%) in RG82, RG89, RG111, RG1437 with KI spray (Table 8). Genotypes with <30% reduction in HI with KI spray included: RG72, RG82, RG89, RG 111, RG 298, RG1437, RG 1494, RG1826, RG1941, RG2139. HI differences were not significant. When the genotypes were compared for seed yield up to secondaries (as there was tertiary seed yield only in control and in 3 genotypes i.e. RG72, RG298 and RG1826), the genotypes with <30% reduction in seed yield included RG82, RG89, RG111, RG1437, RG1826 and RG298 while <35% reduction in seed yield was observed in RG1494 . Genotypes selected for the study already showed drought tolerance along with good root growth. Among the genotypes, stem reserve mobilization was more in primary or secondary branches or in both the orders in RG 72, RG82, RG 298, RG111, RG1437, RG 1494 and RG 1941. Terminal drought stress reduced seed filling duration as shown by increased temperature in late sown crop of wheat and reduced remobilization to drying sinks (Fisher, 2007).

In the present study, it was established that KI@1% concentration could be used for selecting the genotypes with terminal drought stress tolerance. Using this procedure when a set of genotypes that had been identified to be drought tolerant in our earlier studies (Lakshmamma *et al*., 2010, 2014) were screened, we could identify the genotypes that could stand terminal stress. Thus we have been successful in identifying genotypes that show high HI during terminal stress. The germplasm lines, RG82, RG89, RG111, RG1437, RG1826 and RG298with more seed yield in terminal stress, less seed yield reduction with stress and with low DSI could be very useful in breeding programs aimed at developing lines with terminal stress tolerance. Selection for "p" could not be done as the genotypes were of different maturity durations and it was practically not possible to spray each genotype separately only at 50% filling of tertiary spikes. However, the data holds good for use of the selected genotypes in breeding programs. Future drought tolerance breeding programs need to incorporate partitioning coefficient (p) for better drought tolerance and yield stability.

In conclusion, leaf desiccation, primary seed yield reduction (16%) and partitioning coefficient (p-0.50) was more with 1.0% Potassium iodide (KI) spray at 50% filling of primary spikes and there was less reduction in tertiary seed yield (<30%), high partitioning coefficient (p-0.37). Induction of terminal drought stress with KI @1.0% showed <24% reduction in total seed yield with "p" 0.33. Hence, 1.0% KI was identified as the optimum concentration to screen genotypes for terminal drought stress tolerance. Genotypes RG 72, RG82, RG 298, RG111, RG1437, RG 1494 and RG 1941 were identified to have more stem reserve mobilization in primary or secondary branches or both the orders. Among the studied genotypes, RG82, RG89, RG111, RG1437, RG1826 and RG298 showed <30% reduction in seed yield, RG1494 recorded <35% reduction in seed yield. Genotypes with <30% reduction in HI with KI spray included RG72, RG82, RG89, RG 111, RG 298, RG1437, RG 1494, RG1826, RG1941 and RG2139.

Table 5 Crop growth rate and partitioning coefficient with KI spray at 50% filling of primary/tertiary spikes

KI Conc. (%)	Spray during 50% filling of primary spikes			Spray during 50% filling of tertiary spikes					
	% reduction in primary seed yield	crop growth rate (C)* (kg/ha)	Partitioning coefficient (p)**	KI Conc. (%)	% reduction in tertiary seed yield	crop growth rate (C)* (kg/ha)	Partitioning coefficient (p)**	% reduction in total seed yield	Partitioning coefficient (p)**for total seed yield
0.20	7.5	46.0	0.36	1.00	28.7	41.5	0.37	23.9	0.33
0.40	10.3	43.3	0.37	1.50	60.5	41.2	0.20	30.5	0.25
0.50	9.1	46.2	0.35	2.00	64.3	48.3	0.16	22.3	0.29
0.60	6.5	44.2	0.38	2.50	76.4	45.1	0.11	36.4	0.25
0.80	3.6	39.7	0.44	3.00	68.6	42.7	0.16	32.4	0.28
1.00	15.7	30.7	0.50						
control		49.3	0.33	control		45.4	0.47		0.39
water	0.8	39.6	0.40	water	4.0	39.3	0.53	8.8	0.42

C* = TDM/duration p**= (yield/ duration of growth after the start of 50%filling)/C

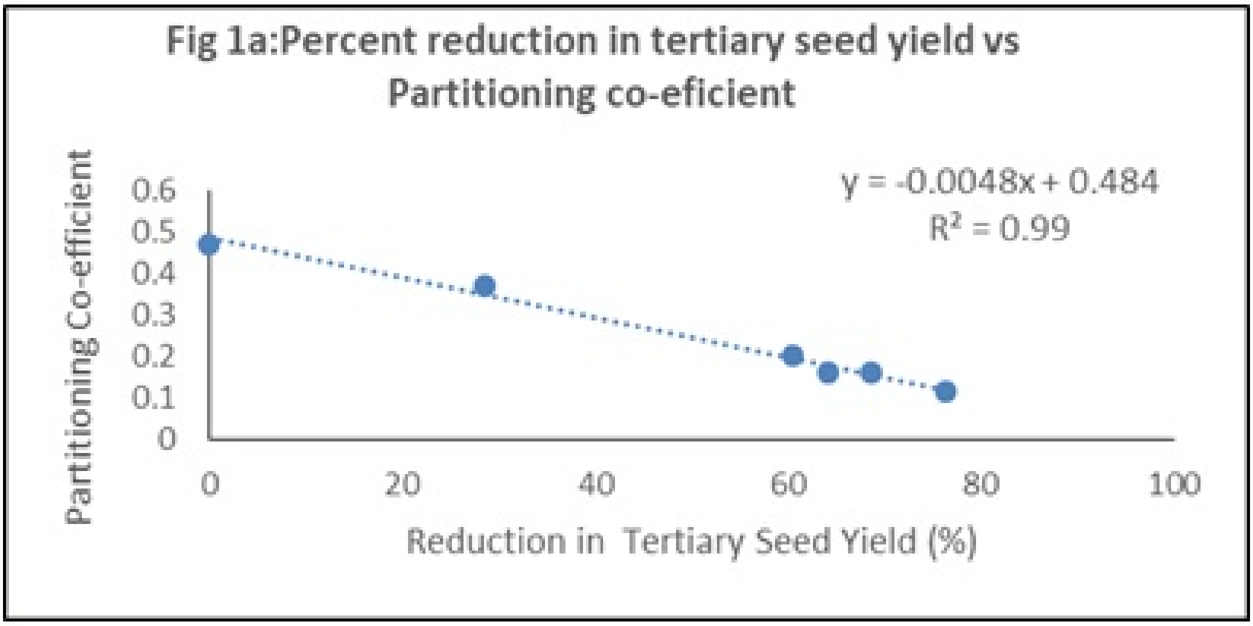
Fig 1a:Percent reduction in tertiary seed yield vs Partitioning co-eficient

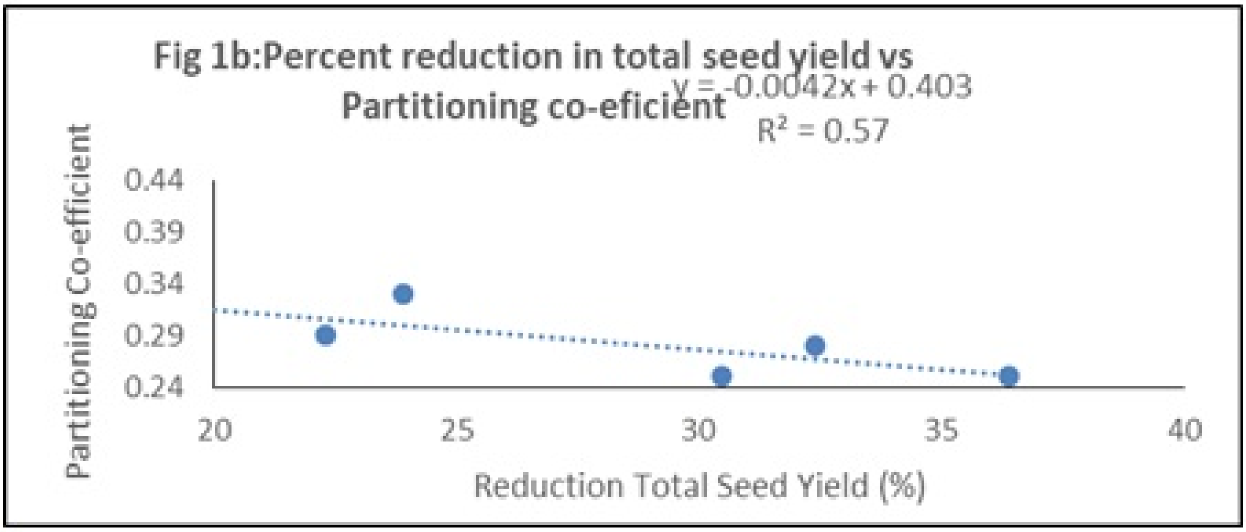

Fig 1b:Percent reduction in total seed yield vs Partitioning co-eficient

Table 6. Dry matter partitioning with KI spray at 20 days after spraying and at harvest

Character (g/plant)	20 days after spraying (g/plant)			At harvest		
	Control	KI spray	% reduction	Control	KI spray	% reduction
Total stem dry weight	45.1	44.6	1.1	65.0	47.2	24.4
Total leaf dry weight	19.7	15.6	20.8	16.5	3.5	78.8
Total spike dry weight	88	69	21.6			
TDM	153	129	15.7	240.0	149.0	32.4
Yield						
Primary seed yield				46.1	33.4	27.5
Secondary seed yield				42.2	22.5	46.7
Tertiary seed yield				5.7	0	100.0
Total seed yield				94.0	55.8	31.8
HI (%)				38.9	37.4	2.0

Table 7 Genotypic differences in stem reserve mobilization and TDM at harvest

Genotype	Stem weight (g/pl.)			TDM (g/pl.)		
	Control	KI spray	% reduction	Control	KI spray	% reduction
RG27	68.7	93.3	-35.8	277.7	169.3	24.2
RG72	89.2	36.4	59.2	329.3	160.5	52.9
RG82	44.1	40.3	8.6	152.3	162.3	-3.2
RG89	67.1	51.5	23.3	164.5	154.4	11.1
RG111	45.4	33.4	26.5	161.3	128.9	21.5
RG298	52.9	45.4	14.3	223.8	119.0	40.6
RG1437	72.1	50.2	30.4	190.6	139.0	28.0
RG1494	48.6	45.4	6.5	200.8	163.4	16.3
RG1826	44.9	30.2	32.8	233.8	130.6	42.3
RG1941	93.6	47.6	49.1	244.2	117.0	51.3
RG2139	71.6	51.9	27.5	275.4	151.2	41.5
RG2797	92.8	53.5	42.3	344.0	128.3	58.4
48-1	64.8	24.2	62.7	281.6	158.2	47.4
DCH-519	54.0	57.5	-6.5	273.3	198.4	21.8
Max.	93.6	93.3	62.7	344.0	198.4	58.4
Min.	44.1	24.2	-35.8	152.3	117.0	-3.2
Mean	65.0	47.2	24.4	239.5	148.6	32.4
		$p < 0.05$			$p < 0.05$	

Table 8 Genotypic differences in total seed yield and HI with KI spray

Genotype	Total seed yield (g/plant)			HI (%)		
	Control	KI spray	% reduction	Control	KI spray	% reduction
RG27	114.6	36.0	68.6	41.3	21.2	58.6
RG72	138.1	66.5	51.9	41.9	41.4	-2.3
RG82	58.9	59.7	-1.3	38.7	36.8	1.9
RG89	47.0	94.8	-101.6	28.6	61.4	-126.7
RG111	73.0	53.0	27.4	45.2	41.1	7.5
RG298	88.0	42.6	51.6	39.3	35.8	18.6
RG1437	68.3	49.2	27.9	35.9	35.4	-0.1
RG1494	78.4	52.0	33.7	39.1	31.8	20.8
RG1826	111.6	64.2	42.4	47.7	49.2	0.2
RG1941	60.8	26.1	57.0	24.9	22.3	11.8
RG2139	123.4	54.6	55.8	44.8	36.1	24.5
RG2797	146.1	32.7	77.6	42.5	25.5	46.2
48-1	96.3	72.3	24.9	34.2	45.7	-42.6
DCH-519	111.3	78.2	29.8	40.7	39.4	10.2
Max.	146.14	94.82	77.6	47.7	61.4	58.6
Min.	47.04	26.12	-101.6	24.9	21.2	-126.7
Mean	94.0	55.8	31.8	38.9	37.4	2.0
		$p < 0.05$			$p > 0.05$	

REFERENCES

Anbessa Y, Warkentin T, Bueckrt R, Vandenberg A and YanTai G 2007. Post flowering drymatter accumulation and partitioning and timing of crop maturity in chickpea in Western Canada. *Canadian Journal of Plant Sciences*, **87**: 233-240.

Ashok K Singh, Aaaheesh Singh, Alok K Singh, Md Shamim, Prashant Vikram, Sanjay Singh and Ghanshyam Chaturvedi 2012. Application of potassium iodide as a new agent for screening of drought tolerance upland rice genotypes at flowering stage. *Plant Knowledge Journal*, **1** (1): 25-32.

Blum A, Mayer J and Gozlan G 1983. Chemical desiccation of wheat plants as a simulator of post anthesis stress II. Relations to drought stress. *Field Crops Research*, **6**: 149-155.

Blum A, Poyarkova H, Golan G and Mayer J 1983a. Chemical desiccation of wheat plants as a simulator of post anthesis stress. I. Effects on translocation and kernal growth. *Field Crops Research*, **6**: 51-58.

Blum A 1998. Improving wheat grain filling under stress by stem reserve mobilization. *Euphytica*, **100**: 77-83.

Condon A G, Richards R A, Rebetzke G J and Farquhar G D. 2004. Breeding for high water-use efficiency. *Journal of Experimental Botany*, **55**: 2447-2460.

Denison R F. 2009. Darwinian agriculture: real, imaginary and complex trade-offs as constraints and opportunities. In: Sadras, V.O., Calderini, D.F. (Eds.), *Crop Physiology - Applications for Genetic Improvement and Agronomy.* Academic Press, Amsterdam, pp. 215-234.

Fisher R A 2007. Understanding the physiological basis of yield potential in wheat. *Journal of Agricultural Sciences*, **145**: 99-113

Gregory S. McMaster, Wilhelm W W 1997. Growing degree-days: one equation, two interpretations. *Agricultural and Forest Meteorology*, **87** (4): 291-300.

Krishnamurthy L, Johansen C and Sethi S C. 1999. Investigation of factors determining genotypic differences in seed yield of non irrigated and irrigated chickpea using a physiological model of yield determination. *Journal of Agronomy and Crop Science*, **183**: 9-17.

Krishnamurthy L, Kashiwagi J, Upadhyaya H D, Gowda C L L, Gaur P M, Sube Singh, Purushothaman R and Varshney R K. 2013. Partitioning Coefficient - A trait that contributes to drought tolerance in Chickpea. *Field Crops Research*, **149**: 354-365.

Lakshmamma P, Alivelu K, Lakshmi Prayaga, Lavanya C and Vishnuvardhan Reddy A 2017. Accurate estimation of biomass production and partitioning efficiency in castor (*Ricinus communis* L.). *Journal of Oilseeds Research*, **34**(4) : 212-216.

Lakshmamma P, Lakshmi Prayaga, Anjani K and Lavanya C. 2010. Identification of castor genotypes for water use efficiency (WUE) and root traits. *Journal of Oilseeds Research (special issue)*, **27**: 187-189

Lakshmamma P. 2014. Confirmation of drought tolerance of good root genotypes for drought tolerance. *Annual Report,* ICAR-DOR 2014-15, pp 22.

Liv S. Severino, Dick L. Auld. 2013. A framework for the study of the growth and development of castor plant. *Industrial Crops and Products*, **46**: 25- 38.

Plaut Z, Butoe B J, Bluementhal C S and Wrigley C W 2004. Transport of dry matter into developing wheat kernels and its contribution to grain yield under post anthesis water deficit and elevated temperature. *Field Crops Research*, **86**: 185-198.

Senshan Yang, Joanne Logan, David L. Coffey 1995. Mathematical formulae for calculating the base temperature for growing degree days. *Agricultural and Forest Meteorology*, **74**: 61-74

Tyagi P K, Singh D P and Pannu P K 2000. Effect of post anthesis desiccation on plant water relation, canopy temperature, photosynthesis and grain yield in wheat genotypes. *Annals of Biology*, **16**: 111-119.

Wardlaw I F and Eckhardt L 1987. Assimilate movement in Iodium and sorghum leaves. IV. Photosynthesis responses to reduce translocation and leaf storage. *Australian Journal of Plant Physiology*, **14**: 573-591.

Yang J, Zhang J, Wang Z, Zhu Q and Liu L 2001. Water deficit induced senescence and its relationship to the remobilization of pre stored carbon in wheat during grain filling. *Agronomy Journal*, **93** (1): 196-206.