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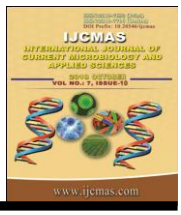

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Plant Growth Retardants Improve Sink Strength and Yield of Sunflower

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A B S T R A C T

KBSH-44, a public sector sunflower hybrid has high biomass production capacity with yield comparable to other popular hybrids. This hybrid is tall with more stalk weight wherein, photo-assimilates are locked up in vegetative parts with a reduced translocation to their productive structures (seed). Any approach, which reduces the plant height, may improve the translocation efficiency to the seed and thus seed yield. In this context, a field experiment was conducted to reduce the plant height by foliar application of plant growth retardants *viz*., paclobutrazol (PBZ), mepiquat chloride (MPC) and chloromequat chloride (CCC) to improve the sink strength. Application of growth retardants at 39 days after sowing reduced the plant height immediately after the application. However, the plant height recovered by the time of crop maturity. Application of mepiquat chloride twice (39and 52 days after sowing) resulted in increased seed yield (49.8 g plant^{-1}) over the control (35.2 g plant^{-1}) and even over the cycocel or paclobutrazol treatment. The increased seed yield (41.5 %) with mepiquat chloride was due to increased sink strength parameters such as increased seed number (820 seeds per thalamus), test weight (6.01 g 100 seeds) and HI (0.35) over unsprayed control plants.

Introduction

Sunflower has gained popularity worldwide because of its premium oil, recognized for its high polyunsaturated fatty acid content with no cholesterol compared to other vegetable oils (Francois, 1996). Present world consumption of oils is 123.8 million tons and expected to increase to 137 million tons per year in the next decade (ISTA, 2016). Sunflower is the third largest source of vegetable oil worldwide next to soybean and groundnut both in terms of area and production (Yeremenko *et al.*, 2017). In terms of production, the top countries are Ukraine (11.9 million tons), Russia (9.7 mt), European Union (7.72 m t), Argentina (2.7 m t), Turkey (1.1 m t), India (0.52 m t) and others (7.18 million tons) (FAOSTAT, 2017). The global sunflower area is 25.2 million hectares and in India, cultivated in an area of 0.82 million hectares with a production of 0.52 million tons and productivity of 707 kg ha^{-1} (FAOSTAT, 2014). The production of sunflower in India is concentrated in Karnataka, Andhra Pradesh, Maharashtra and Tamil Nadu. Karnataka is the leading state in terms of area and production accounting for 0.42 million hectares and 0.25

million tons with a productivity of 693 kg per ha^{-1} (FAOSTAT, 2014).

The major physiological constraints in sunflower production are excessive vegetative growth, lack of photosynthetic activity during the time of seed filling, poor translocation of photosynthates and poor seed set in the cultivated hybrids (Patil and Dhomne, 1997). In this direction, the sunflower hybrid, KBSH-44 (a public sector hybrid) has high biomass production potential with tall nature of plant and yield comparable to other popularly cultivated hybrids. It is hypothesized that, in this hybrid, a greater proportion of photosynthates are diverted for production and maintenance of vegetative plant parts rather than translocation to reproductive parts and hence, the plant puts on more plant height and higher biomass. Therefore, any attempts to reduce plant height would be expected to improve the seed yield by diverting the photosynthates to reproductive structures which otherwise goes for vegetative growth. In an earlier study, possibility to enhance the seed yield of sunflower by diverting large quantity of biomass locked up in vegetative parts towards seed filling has been reported (Nanja Reddy *et al.,* 2003). Several studies showed that, the plant growth retardants such as paclobutrazol, cycocel, mepiquat chloride and ethephonare capable of reducing plant height and thus increased translocation of photo-assimilates to reproductive structures (seed) in sunflower (Kashid *et al.,* 2010; Spitzer *et al.,* 2011; Polat *et al.,* 2017). Keeping this in view, the field experiment was conducted to investigate the influence of plant growth retardants on plant height and its consequent effect on sink strength and yield of sunflower hybrid, KBSH-44.

Materials and Methods

Field experiments were conducted during *kharif* season 2017 and summer, 2018at All India Coordinated Research Project on sunflower, Zonal Agricultural Research Station, University of Agricultural Sciences, Bengaluru, Karnataka, India situated at 30° North latitude and 77° 35East longitudes with an altitude of 930 meter above mean sea level. The soil is red sandy loam nearly at neutral pH (6.7) and with normal electrical conductivity (0.22 dSm^{-1} 25 °C). The available nitrogen (355 kg ha^{-1}), phosphorus (50.49 kg ha^{-1}) and potassium content (243 kg ha^{-1}) in the soil were medium. Recommended dose of 60:90:60 kg N, P_2O_5, K_2O per hectare in the form of Urea, Di Ammonium Phosphate and Muriate of potash was applied to the soil. Full dose of P and K and; half of the N were applied at the time of sowing and the remaining half of the N was applied at 35 days after sowing. Farm yard manure (FYM) @ 7.5 t $ha^{-1}$was applied 15 days prior to sowing so as to undergo decomposition. Both the experiments were laid out in the randomized complete block design (RCBD). The first experiment consisted of seven treatments with four replications. The treatments were foliar sprays of water, cycocel, paclobutrazol and mepiquat chloride (detailed with data). Regular irrigation and plant protection measures were taken up. Five plants from each replication were selected randomly, various growth and yield parameters were recorded and the data was analyzed using the statistical package, OPSTAT (Sheoran *et al.,* 1998).

Since the higher reduction in plant height was noticed in the first experiment with cycocel, the second experiment was carried out to study the effect of higher concentration (3000 ppm) of chloromequat chloride (cycocel) applied at different growth stages on the plant height in sunflower hybrid, KBSH-44. The experiment consisted eight treatments and three replications. The treatments were control (water spray), application of cycocel at 4 leaves stage, 6 leaves stage, 8 leaves stage, 10 leaves stage, 12 leaves stage, 14 leaves stage and 16 leaves stage. The plant height was measured on 30 and 60th day after sowing.

Results and Discussion

Effect of plant growth retardants on growth parameters

Foliar application of plant growth retardants, cycocel (CCC, 1500 ppm) and paclobutrazol (PBZ, 12.5g a.i./ hectare) on 39th DAS (just prior to star bud stage) reduced the plant height significantly by 12 days after the spray. The cycocel was more effective than other growth retardants. However, several days after application of growth retardants, the plant height was recovered to normal height and hence, the plant height did not differ significantly between the treatments at 60 DAS and at harvest (Table 1). In a similar study, Gayithri (2015) reported that, the application of cycocel at 1500 ppm was not effective in reducing the plant height at flowering and at maturity in sunflower hybrid, KBSH-44, however, higher concentration of cycocel (3000 ppm) reduced the plant height significantly. In another study, Koutroubas *et al.,* (2004) reported that, the foliar application of paclobutrazol (@12.5 g a.i/ha) at 33 DAS and 48 DAS decreased the plant height at 10 days after spray. However the mepiquat chloride (@25g a.i/ha) was not effective to reduce the plant height immediately after spray, but has delayed effect, and reduced the plant height by the time of flowering and at maturity. Such reduced plant height with mepiquat chloride by crop maturity decreased the seed yield significantly. Therefore, application of growth retardants at a lower or normal dose reduces the plant height in a few days after application and recovers by the time of crop maturity. Higher concentration of growth retardants reduces the plant height effectively but has negative effect as it reduces the biomass. In contrast, a temporary reduction in plant height will not alter the biomass production, rather it will be useful to increase the sink strength parameters and seed yield. Based on the earlier reports and also as cycocel was more effective in reducing the plant height (first experiment, Table 1), cycocel (1500 and 3000 ppm) was sprayed at different time intervals to monitor the plant height at 30 and 60 DAS (Table 2). The cycocel (1500 and 3000 ppm at different leaf stages) decreased the plant height soon after the foliar application and tends to recover with time i.e., 30 DAS. The recovery was to a lesser extent at higher concentration of 3000 ppm (Table 2). Therefore, at lower concentration (1500 ppm), plant height was recovered and hence no significant differences by 60 DAS. However, at higher concentration (3000 ppm), the recovery was less and hence remained significant differences in the plant height at 60 DAS. The cycocel @ 3000 ppm was more effective in reducing the plant height irrespective of the stage of application and the effect was long lasting. Such observation of reduced plant height at higher concentration (3000 ppm) of cycocel has also reported by Gayithri (2015). The cycocel being an anti-gibberellin compound it reduces the cell elongation and plant height (Lovett and Orchard, 1974). The results therefore suggest that, the growth retardants at lower concentrations would be useful for a temporary reduction, but increases the partitioning and seed yield.

Foliar application of plant growth retardants did not influence the stem diameter significantly both at 60 DAS and at harvest stage (Table 1). Pathak and Dixit (1994) and Kashid (2008) also noticed no improvement in stem diameter due to foliar application of growth retardants over the control plants.

Number of leaves per plant did not differ significantly due to application of different growth retardants (Table 1). Such observations was also made by Koutroubas *et al.,* (2014) wherein they reported no effect of cycocel, mepiquat chloride and paclobutrazol on number of leaves per plant.

Table.1 Effect of plant growth retardants on plant height, stem diameter, number of leaves per plant and leaf area index (LAI) in sunflower hybrid, KBSH-44

Treatment details	Plant height (cm)			Stem girth (cm)		No. of leaves/ plant	LAI
	52 DAS	60 DAS	Harvest	60 DAS	Harvest	60 DAS	60 DAS
T_1= Control (water spray at 39 and 52 DAS)	175.4	194.4	196.2	2.395	2.345	23.75	3.840
T_2= Cycocel (1500 ppm at 39 DAS)	158.8	184.1	186.4	2.355	2.285	24.75	3.608
T_3= Cycocel (1500 ppm at 39 and 52 DAS)	159.8	183.3	185.1	2.300	2.295	25.00	3.663
T_4= Paclobutrazol (12.5 g a.i /ha at 39 DAS)	162.6	188.4	191.1	2.390	2.305	25.50	4.423
T_5= Paclobutrazol (12.5 g a.i/ha at 39 and 52 DAS)	167.5	191.2	192.6	2.350	2.265	24.75	4.025
T_6= Mepiquat chloride (25.0 g a.i/ha at 39 DAS)	173.3	192.8	194.0	2.370	2.310	25.25	4.193
T_7= Mepiquat chloride (25.0 g a.i/ha at 39 and 52 DAS)	167.0	186.1	187.5	2.355	2.285	25.25	3.995
Mean	**166.3**	**188.6**	**190.4**	**2.359**	**2.299**	**24.89**	**3.964**
SEm±	3.2	3.6	3.4	0.052	0.040	0.49	0.159
CD @ 5%	9.4	NS	NS	NS	NS	NS	0.475
C.V. %	3.8	3.9	3.6	4.416	3.490	3.96	8.0

Note: Date of sowing (04-10-2017), 1st spray was given on 12-11-2017 coinciding with 8 leaf stage & just prior to star bud formation (39 DAS)and 2nd spray was given on 25-11-2017 (52 DAS i.e., nearly 10 days after star bud stage)

Table.2 Effect of chloromequat chloride (cycocel) spray on plant height in sunflower hybrid, KBSH-44

Treatment (Leaf stage at which spray was taken)	Days after sowing	Plant height at 30 DAS (cm)		Plant height at 60 DAS (cm)	
		1500 ppm	3000 ppm	1500 ppm	3000 ppm
4 (Water)	13	67.00	67.00	202.89	205.89
4	13	62.22	60.78	190.44	187.56
6	17	58.00	55.33	180.11	179.44
8	21	58.22	54.33	190.78	185.11
10	25	59.00	54.33	196.11	189.11
12	29			189.56	184.89
14	33			190.33	180.00
16	37			197.78	191.56
Mean		**60.89**	**58.35**	**188.50**	**187.95**
SEm±		1.22	1.32	4.95	3.33
CD @ 5%		3.50	3.77	NS	9.47
C.V. (%)		6.05	6.87	7.72	5.32

Note: Date of sowing (28-03-2018), 1st spray was given on 11-04-2018 coinciding with 4 leaf stage and continued subsequently with an interval of four days.

Table.3 Effect of growth retardants on yield and yield attributes in sunflower hybrid, KBSH-44

Treatments	Leaf dry weight (g pl^{-1})	Stem dry weight (g pl^{-1})	Thalamus dry weight (g pl^{-1})	Head diameter (cm)	100 seed weight (g)	No. of seeds/ thalamus	TDM (g pl^{-1})	HI	Seed weight (g pl^{-1})
T_1= Control (water spray at 39 and 52 DAS)	28.28	41.7	15.4	13.8	5.23	673.9	120.6	0.295	35.2
T_2= Cycocel (1500 ppm at 39 DAS)	30.03	40.3	15.2	13.9	5.47	715.0	124.5	0.313	39.0
T_3= Cycocel (1500 ppm at 39 and 52 DAS)	26.30	39.3	16.0	13.5	5.66	649.0	118.2	0.310	36.7
T_4= Paclobutrazol (12.5 g a.i /ha at 39 DAS)	29.50	42.9	14.7	13.8	5.85	661.2	125.6	0.308	38.6
T_5= Paclobutrazol (12.5 g a.i/ha at 39 and 52 DAS)	28.45	41.9	15.8	13.9	5.57	723.3	126.4	0.323	40.2
T_6= Mepiquat chloride (25.0 g a.i/ha at 39 DAS)	31.83	35.5	15.5	14.0	5.67	743.1	125.0	0.348	42.1
T_7= Mepiquat chloride (25.0 g a.i/ha at 39 and 52 DAS)	30.95	44.5	15.8	14.2	6.01	819.9	141.0	0.350	49.8
Mean	**29.33**	**40.9**	**15.5**	**13.9**	**5.64**	712.3	**125.9**	**0.321**	**40.2**
SEm±	1.52	4.02	0.53	0.27	0.09	36.5	5.89	0.02	2.57
CD @ 5%	NS	NS	NS	NS	0.28	NS	NS	NS	7.69
C.V. %	10.37	19.7	6.89	3.9	3.34	10.2	9.35	11.0	12.8

Note: Date of sowing (04-10-2017), 1st spray was given on 12-11-2017 coinciding with 8 leaf stage & just prior to star bud formation (39 DAS)and 2nd spray was given on 25-11-2017 (52 DAS i.e., nearly 10 days after star bud stage)

The leaf area index (LAI) did not decrease significantly over the control, instead the LAI was increased with paclobutrazol and mepiquat chloride. Similar to our results, Gayithri (2015) also reported higher LAD (132.7 days) with paclobutrazol at 12.5 g ha^{-1} and a minimum LAD (108.3 days) in cycocel (1500 ppm). The maintenance of higher LAI may be due to delayed leaf senescence, prevention of chlorophyll degradation and protease activity (Kashid, 2008) and such higher LAI would maintain the photosynthetic activity for a longer period with optimum concentration of growth retardants and lead to higher productivity.

Effect of plant growth retardants on yield parameters

Crop yield is the result of assimilates synthesized during the growing period and its allocation to the reproductive structures (source-sink relationship). The total dry matter is an important component of the seed yield and the components of dry matter *viz*., weight of leaf, stem and thalamus at the time of crop harvest did not differ significantly between the treatments. However, these parameters were higher by 16.9 %, 9.4 %, 6.7% and2.6% respectively when mepiquat chloride was applied at 39 and 52 DAS (Table 3), suggests that, the growth retardants at an optimum concentration do not affect the biomass production and hence any improvement sink parameters without affecting the total biomass would enhance the seed yield of sunflower significantly.

Higher diameter of thalamus would be required to accommodate higher seed number and seed yield. No significant differences between the treatments were observed for thalamus size (Table 3). Similar to our results, no improvement in head diameter was obsrerved with normal concentration of growth retardants and whereas, higher concentration reduced the thalamus size (Koutroubas *et al.*, 2014; Gayithri, 2015 and Polat *et al.*, 2017). Further, increase in diameter may lead to increased storage of carbohydrates in the thalamus rather than translocation to seed. Therefore, without any increase in head diamter, accommodating the higher seed number with no central sterility would a better option for higher yields.

The major sink strength parameters *viz*., the test weight and seed number are the important determinants for achieving the higher seed yield. Application of MPC (@25 ga.i. ha^{-1}) at 39 and 52 DAS increased the test weight by 14.9 % and seed number by 21.7 % as compared to the control (Table 3). Our results are in conformity with the findings of Kashid *et al.*, (2010) and Sable *et al.*, (2015), suggesting that the growth retardants at an appropriate dosage and time improves the sink strength.

The seed yield was higher in all the growth retardant treatments as compared to the control and it was significantly superior when the mepiquat chloride was applied 39 and 52 DAS (49.8 g $plant^{-1}$) as compared to control (35.2 g $plant^{-1}$). Thalamus size remaining similar between the treatments, the improved sink strength parameters with the application of mepiquat chloride might have improved central fertility in addition to seed number, test weight, and thus lead to higher seed yield. Similar reports of increased seed yield with mepiquat chloride (300 ppm) has been reported by Anitha *et al.*, (2007), Sawan *et al.*, (2007) and Polat *et al.*, (2017). These results suggest that, the mepiquat chloride could be a better growth retardant as compared to CCC or paclobutrazol for increasing the seed yield of sunflower.

Exogenous application of plant growth retardants at 39 DAS (nearly at initiation of star bud) at an appropriate concentration

would reduce the plant height temporarily and recovers with time. However, application of growth retardant, mepiquat chloride (at the rate of 25 g ha^{-1}) at 39 and 52 DAS improves the sink strength (seed number and seed filling) and increases the seed yield of high biomass producing sunflower hybrids, like KBSH-44. It appears that temporary reduction in plant height at star bud stage would help in higher translocation of photosynthates to seed without affecting the total biomass and hence the higher seed yield with growth retardant.

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