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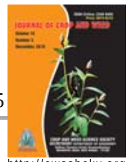

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Efficacy of pendimethalin against resistant little seed canary grass as affected by soil moisture and formulation

[1]M. KAUR, S. S. PUNIA, J. SINGH AND S. SINGH

Department of Agronomy, CCS Haryana Agricultural University, Hisar -125004, India

[1] Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana-141004

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ABSTRACT

A pot study was conducted at CCSHAU, Hisar during the winter seasons of 2014-15 and 2015-16 to evaluate the effect of soil moisture (75 and 100% of field capacity) on the efficacy of two formulations of pendimethalin i.e. emulsifiable concentrate and capsule suspension applied as pre-emergence (alone) and post-emergence (tank-mix with metribuzin) against resistant and sensitive populations of P. minor. Results revealed that the Emulsifiable concentrate formulation of pendimethalin when applied as pre-emergence had reduced control of resistant and sensitive P. minor populations at 75% of field capacity as compared to control. Capsule suspension formulation of pendimethalin sprayed as pre-emergence gave absolute control of sensitive as well as resistant P. minor at both the field capacity based soil moisture treatments. Both the formulations applied as post-emergence (tank-mix with metribuzin) exhibited similar response as that of individual application. The results are of practical significance in field when dry soil conditions are a concern.

Keywords: Formulation, metribuzin, pendimethalin, *Phalaris minor*, soil moisture, wheat

Phalaris minor Retz. (littleseed canarygrass) is the ubiquitous and the most pernicious weed infesting the crop of wheat in rice-wheat crop rotation prevailing in the Indo-gangetic north-western regions of India. The problem of *P. minor* is most common in grain baskets of the country *i.e.* Punjab and Haryana where in rice-wheat is the major crop sequence (Punia *et al*., 2017). The morphological similarities of *Phalaris minor* with respect to wheat crop, its capacity to produce abundant seeds, tendency to continuously shatter seeds before wheat harvesting have ensured its high pervasiveness in wheat crop. In India, *P. minor* control is unfortunately entirely reliant on crop-selective post-emergence herbicides *viz.* isoproturon (photosystem II inhibitor), fenoxaprop, clodinafop and pinoxaden (acetyl-coA-carboxylase inhibitor), sulfosulfuron and pre-mix of mesosulfuron + iodosulfuron (acetolactate synthase inhibitor). Heavy dependence on herbicides alone with total disregard to the principles of integrated weed management has led to the nuisance of resistance to herbicides in *P. minor*. Presently, some *P. minor* populations infesting the wheat fields of Punjab and Haryana have developed multiple herbicide resistance to different herbicides (Chhokar and Sharma, 2008).

Fortunately, resistant *P. minor* populations have been found sensitive to group K herbicides *viz.* pendimethalin and trifluralin. Globally, also the number of weed populations resistant to group K herbicides is low (Heap, 2016). Hence, providing an alternative mode of action, pendimethalin is an important compound for the control of ACCase and ALS resistant weed populations and for the prevention of herbicide resistance development.

Email : maninder.sindhu@yahoo.com

However, in field inconsistent weed control with pendimethalin due to preparation of land and presence of adequate soil moisture is a concern (Singh, 2015). Adequate soil moisture is a pre-requisite for pre-emergence herbicides as it affects equally the efficacy of herbicide and phytotoxicity on crop by affecting herbicide absorption, metabolism or translocation (Chauhan and Johnson, 2011). When moisture in soil is not enough, the pre-emergence herbicides reduces their effectiveness considerably as the molecules get strongly adsorbed by the soil particles thus rendering them inaccessible for uptake by the weeds (Zanatta *et al*., 2008). In a silty clay loam, emulsifiable concentrate pendimethalin was found to be more toxic to *Avena sativa* L. than micro-encapsulated formulation. Further, ME formulation showed prolonged presence possibly owing to slowed release of the chemical (Hatzinikolaou *et al*., 2004).

Meager information is available regarding the behavior of CS formulation of pendimethalin in dry soil conditions. The present study was therefore conducted in pots in screen house to evaluate CS and EC formulations of pendimethalin for their effectiveness against resistant *P. minor* as influenced by soil moisture conditions.

MATERIALS AND METHODS

Experimental details

Pot culture experiments were conducted at CCSHAU, Hisar during two consecutive winter seasons of 2014-15 and 2015-16. Treatments included two formulations of pendimethalin *viz.* capsule suspension (CS) and emulsifiable concentrate (EC). These were applied either as alone or tank mixed with metribuzin as PRE and early post-emergence (EPOE) at two moisture levels *i.e.* optimum and limited moisture levels. The optimum moisture was attained by keeping the soil at field capacity while limited soil moisture level was achieved by keeping the soil at 75% of field capacity. Two populations of *P. minor*, one having resistance and the other being susceptible to herbicides, were selected to study the efficacy of pendimethalin as influenced by soil moisture and herbicide formulation. Wheat '*WH 711*' was used for the phytotoxicity study. The pots were filled with the soil which was taken from the agronomy research farm. A field which remained unsprayed and was weed free was used for digging out soil for pot filling. Further, the soil was prepared by air-drying, crushing and grinding to 2 mm size. A mixture of 5 kg soil and vermi-compost (4:1) was used for filling the earthen pots (93 diameter). A measured quantity of water was used to irrigate the pots in order to achieve the desired moisture levels as per treatments and PRE herbicide treatments were sprayed. The remaining pots were irrigated uniformly to have optimal soil moisture. Sowing of crop and *P. minor* was done on the 26th of November in 2014 and 27th of November during 2015, respectively. The number of seeds used per pot was 25 each for the crop and *P. minor*. Being small seeded *P. minor* was sown at a depth of 0.5-1.0 cm while wheat was sown at a depth of 5 cm. A day before sowing PRE herbicides were sprayed as per treatments. At 20 days after sowing, EPOE herbicides were sprayed after the pots have been irrigated with measured amounts of water to achieve the desired moisture levels as per the treatments. Unsprayed plants were used as control for comparison. Independent experiments were conducted on wheat and resistant and susceptible *P. minor* populations in completely randomized design (CRD) with four replications.

Data collection

Efficacy study

At 30, 45 and 60 DAS, the observations on visual percentage control of *P. minor* was recorded. A scale on 0-100% (0 as 0% control and 100 as 100% control) was used for rating *P. minor* control. The comparison of each treatment was made with control (unsprayed) for recording the data on visual percentage control. For recording dry weight accumulation by the plants, 5 plants were selected at random in every pot. The plants were removed from just above the surface of the soil at three weeks after sowing. After sun-drying, the plants were oven dried at 60±5^{0}C to achieve constant weight. The final dry weight was then averaged over five plants and expressed as g plant^{-1}. At 30 DAS, in each pot, plant height of the selected plants was recorded from base of the plant to top of the main shoot. The height was then averaged and given in centimeters. Similarly, for each pot, a count of leaves on the same plants was taken and average of five plants was worked out and given as leaves plant^{-1}. The data on number of ear heads was recorded 60 DAS from five random plants in each pot. The data were averaged over five plants and given as ear heads plant^{-1}.

Phyto-toxicity study

Phyto-toxic symptoms on wheat were recorded visually after 10 and 20 days of herbicide spray. These symptoms were rated using a scale of 0-10 in which 0 as no mortality and 10 as complete mortality was considered. From each pot, 5 plants were selected at random for recording the observations on growth attributes and these observations were recorded as mentioned for *P. minor.*

Data analysis

For each species, the data were analyzed separately. The data on percent visual control and dry weight of weed were arcsine and square root transformed, respectively before analysis. The data were analyzed adopting an analysis of variance (ANOVA) technique. Significant differences among the treatments were determined with the help of Fisher's least significance difference (LSD) test at 5% level of significance using the statistical computer programme 'OPSTAT' (http:/ hau.ernet.in/about/opstat.php). The data were analysed separately for each year.

RESULTS AND DISCUSSION

Efficacy study

The data in table 1 reveals that emulsifiable concentrate (EC) formulation of pendimethalin and metribuzin sprayed as pre-emergence (PRE) had significantly reduced percent visual control of resistant population of *P. minor* in limiting moisture conditions in comparison to their application in optimum moisture conditions. There was 42-62, 23-48 and 35-55 % less control of *P. minor* at 30 days after sowing (DAS), respectively with pendimethalin EC, pendimethalin EC + metribuzin and metribuzin applied as PRE. However, complete weed control was observed with capsule suspension (CS) pendimethalin sprayed as PRE in both moisture levels. Pendimethalin CS sprayed as EPOE also gave absolute control of resistant population of *P. minor* in both moisture levels. Whereas, pendimethalin EC + metribuzin sprayed as EPOE registered lesser weed control in limited soil moisture level in comparison to full weed control in optimal moisture level during 2015-16 (Fig. 1). The weed dry weight was significantly affected by herbicide treatments (Table 2). Weed dry weight at 30 DAS was observed to be zilch with PRE pendimethalin CS at both the soil moisture levels. On

Table 1: Visual control of resistant *P. minor* population under different treatments

Treatments	Dose (g ha^{-1})	Visual control (%) 30 DAS	
		2014-15	2015-16
Pendimethalin EC at field capacity, PRE	1000	90.0 (100)	90.0 (100)
Pendimethalin EC at 75% field capacity, PRE	1000	49.9 (58)	38.2 (38)
Pendimethalin CS at field capacity, PRE	1000	90.0 (100)	90.0 (100)
Pendimethalin CS at 75% field capacity, PRE	1000	90.0 (100)	90.0 (100)
Metribuzin at field capacity, PRE	150	90.0 (100)	90.0 (100)
Metribuzin at 75% field capacity, PRE	150	53.8 (65)	42.1 (45)
Metribuzin at field capacity, EPOE	150	19.9 (12)	6.1 (3)
Metribuzin at 75% field capacity, EPOE	150	19.9 (12)	10.4 (5)
Pendimethalin EC + metribuzin at field capacity, PRE	1000 + 150	90.0 (100)	90.0 (100)
Pendimethalin EC + metribuzin at 75% field capacity, PRE	1000 + 150	61.3 (77)	45.9 (52)
Pendimethalin EC + metribuzin at field capacity, EPOE	1000 + 150	10.4 (5)	4.3 (2)
Pendimethalin EC + metribuzin at 75% field capacity, EPOE	1000 + 150	22.6 (15)	19.2 (11)
Pendimethalin CS + metribuzin at field capacity, PRE	1000 + 150	90.0 (100)	90.0 (100)
Pendimethalin CS + metribuzin at 75% field capacity, PRE	1000 + 150	90.0 (100)	90.0 (100)
Pendimethalin CS + metribuzin at field capacity, EPOE	1000 + 150	16.6 (8)	12.9 (5)
Pendimethalin CS + metribuzin at 75% field capacity, EPOE	1000 + 150	19.9 (12)	15.4 (7)
Untreated (control)	-	0.0 (0)	0.0 (0)
LSD (0.05)	**–**	**6.2**	**7.5**

Note : Original percentage values (in parentheses) are subjected to Sin transformation before data analysis

Table 2: Dry weight of resistant *P. minor* as influenced by different treatments at 30 DAS

Treatments	Dose (g ha^{-1})	Dry weight (g plant^{-1}) 30 DAS	
		2014-15	2015-16
Pendimethalin EC at field capacity, PRE	1000	1.0 (0.0)	1.0 (0.0)
Pendimethalin EC at 75% field capacity, PRE	1000	1.07 (0.16)	1.09 (0.18)
Pendimethalin CS at field capacity, PRE	1000	1.0 (0.0)	1.0 (0.0)
Pendimethalin CS at 75% field capacity, PRE	1000	1.0 (0.0)	1.0 (0.0)
Metribuzin at field capacity, PRE	150	1.0 (0.0)	1.0 (0.0)
Metribuzin at 75% field capacity, PRE	150	1.03 (0.07)	1.08 (0.16)
Metribuzin at field capacity, EPOE	150	1.10 (0.21)	1.14 (0.29)
Metribuzin at 75% field capacity, EPOE	150	1.07 (0.14)	1.12 (0.25)
Pendimethalin EC + metribuzin at field capacity, PRE	1000 + 150	1.0 (0.0)	1.0 (0.0)
Pendimethalin EC + metribuzin at 75% field capacity, PRE	1000 + 150	1.01 (0.03)	1.05 (0.09)
Pendimethalin EC + metribuzin at field capacity, EPOE	1000 + 150	1.12 (0.25)	1.15 (0.31)
Pendimethalin EC + metribuzin at 75% field capacity, EPOE	1000 + 150	1.06 (0.13)	1.12 (0.27)
Pendimethalin CS + metribuzin at field capacity, PRE	1000 + 150	1.0 (0.0)	1.0 (0.0)
Pendimethalin CS + metribuzin at 75% field capacity, PRE	1000 + 150	1.0 (0.0)	1.0 (0.0)
Pendimethalin CS + metribuzin at field capacity, EPOE	1000 + 150	1.11 (0.22)	1.17 (0.36)
Pendimethalin CS + metribuzin at 75% field capacity, EPOE	1000 + 150	1.08 (0.18)	1.14 (0.30)
Untreated (control)	-	1.14 (0.30)	1.17 (0.38)
LSD (0.05)	**–**	**0.05**	**0.04**

Note : Original percentage values (in parentheses) are subjected to Sin transformation before data analysis

Table 3: Phyto-toxicity on wheat under different treatments

Treatments	Dose ($g\ ha^{-1}$)	Phyto-toxicity (0-10 scale) 20 DAS	
		2014-15	2015-16
Pendimethalin EC at field capacity, PRE	1000	0	0
Pendimethalin EC at 75% field capacity, PRE	1000	0	0
Pendimethalin CS at field capacity, PRE	1000	0	0
Pendimethalin CS at 75% field capacity, PRE	1000	0	0
Metribuzin at field capacity, PRE	150	6	5
Metribuzin at 75% field capacity, PRE	150	6	6
Metribuzin at field capacity, EPOE	150	0	0
Metribuzin at 75% field capacity, EPOE	150	0	0
Pendimethalin EC + metribuzin at field capacity, PRE	1000 + 150	4	3
Pendimethalin EC + metribuzin at 75% field capacity, PRE	1000 + 150	5	5
Pendimethalin EC + metribuzin at field capacity, EPOE	1000 + 150	0	0
Pendimethalin EC + metribuzin at 75% field capacity, EPOE	1000 + 150	0	0
Pendimethalin CS + metribuzin at field capacity, PRE	1000 + 150	5	3
Pendimethalin CS + metribuzin at 75% field capacity, PRE	1000 + 150	5	5
Pendimethalin CS + metribuzin at field capacity, EPOE	1000 + 150	0	0
Pendimethalin CS + metribuzin at 75% field capacity, EPOE	1000 + 150	0	0
Untreated (control)	-	0	0

Table 4: Plant height and dry weight of wheat as influenced by different treatments

Treatments	Dose ($g\ ha^{-1}$)	Plant height (cm) 30 DAS		Dry weight ($g\ plant^{-1}$) 30 DAS	
		2014-15	2015-16	2014-15	2015-16
Pendimethalin EC at field capacity, PRE	1000	33	37	0.40	0.52
Pendimethalin EC at 75% field capacity, PRE	1000	28	29	0.27	0.40
Pendimethalin CS at field capacity, PRE	1000	32	36	0.41	0.56
Pendimethalin CS at 75% field capacity, PRE	1000	25	27	0.28	0.38
Metribuzin at field capacity, PRE	150	30	35	0.38	0.45
Metribuzin at 75% field capacity, PRE	150	25	28	0.33	0.34
Metribuzin at field capacity, EPOE	150	32	34	0.40	0.51
Metribuzin at 75% field capacity, EPOE	150	24	30	0.30	0.38
Pendimethalin EC + metribuzin at field capacity, PRE	1000 + 150	34	36	0.47	0.50
Pendimethalin EC + metribuzin at 75% field capacity, PRE	1000 + 150	25	28	0.35	0.33
Pendimethalin EC + metribuzin at field capacity, EPOE	1000 + 150	33	38	0.43	0.57
Pendimethalin EC + metribuzin at 75% field capacity, EPOE	1000 + 150	24	34	0.29	0.34
Pendimethalin CS + metribuzin at field capacity, PRE	1000 + 150	35	34	0.40	0.49
Pendimethalin CS + metribuzin at 75% field capacity, PRE	1000 + 150	24	31	0.30	0.30
Pendimethalin CS + metribuzin at field capacity, EPOE	1000 + 150	31	36	0.41	0.53
Pendimethalin CS + metribuzin at 75% field capacity, EPOE	1000 + 150	25	33	0.38	0.40
Untreated (control)	-	35	36	0.48	0.57
LSD (0.05)		**6**	**5**	**0.09**	**0.11**

the other hand, when compared to unsprayed plants there was 10-53% dry weight accumulation by *P. minor* sprayed with EC pendimethalin under limited moisture conditions. The plants of resistant *P. minor* accumulated 23-42% dry weight when these were sprayed with PRE metribuzin applied at 75% of field capacity over untreated plants (control). EPOE herbicides were sprayed 25 DAS and the data were recorded 30 DAS and hence weed dry weight remained statistically similar to that of untreated control.

Figure 2 shows data on growth parameters of *P. minor*. Due to full control of *P. minor* with PRE pendimethalin CS at both soil moisture levels and with PRE pendimethalin EC at optimum soil moisture level therefore data on growth parameters with regard to these treatments were none. At 30 DAS, EC formulation of pendimethalin sprayed as PRE under limited soil moisture level registered the values for different growth parameters which were significantly less over those of the unsprayed plants. Herbicides applied as EPOE

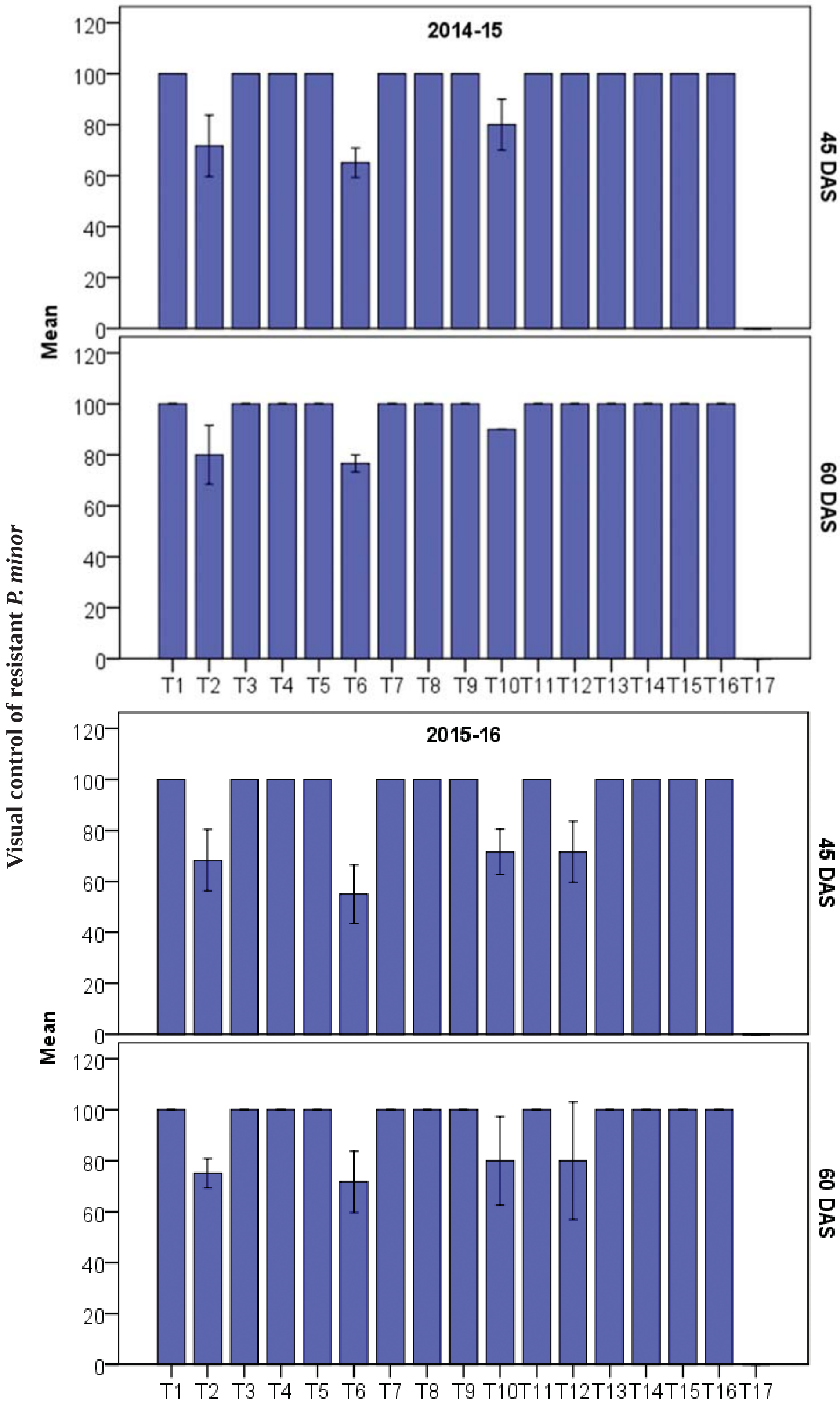

Fig. 1. Visual control of resistant *P. minor* as influenced by different treatments (bars indicate ±S.E. of mean of 4 replicates)

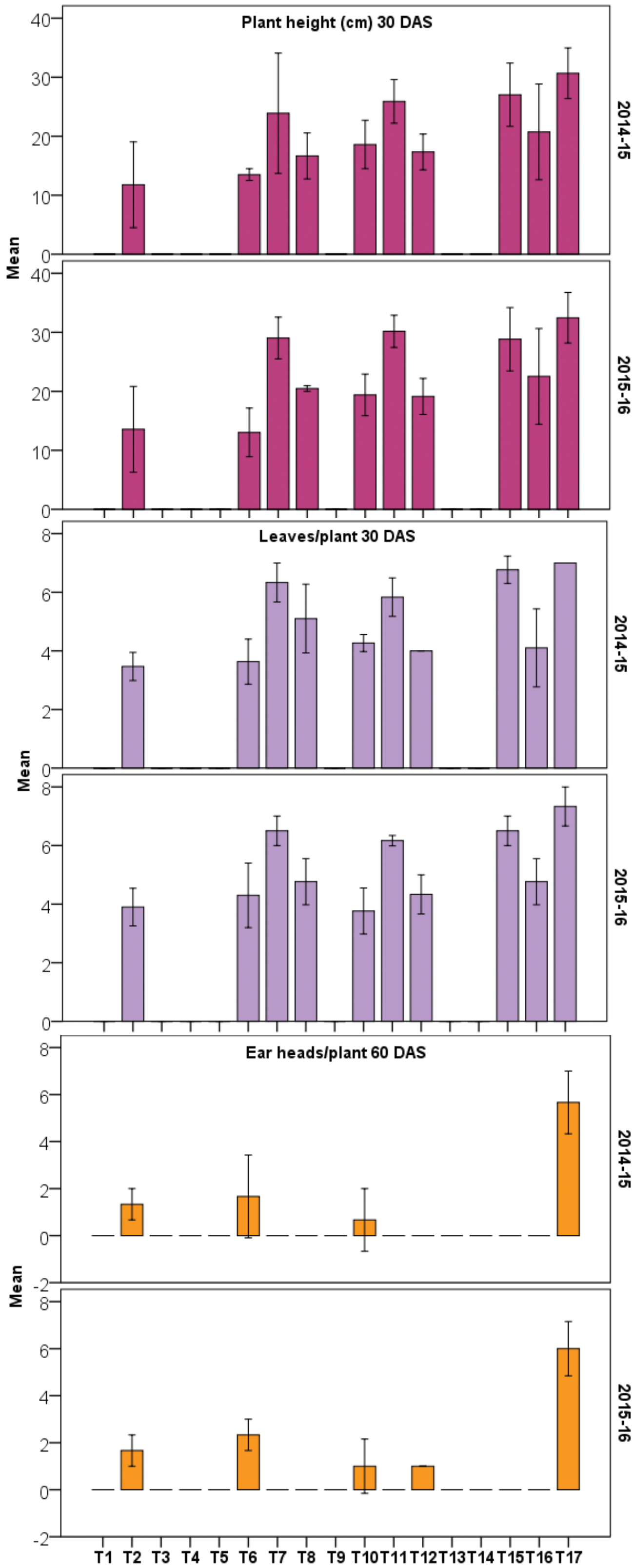

Fig. 2. Plant height, leaves per plant and ear heads per plant of resistant *P. minor* as influenced by different treatments (bars indicate ±S.E. of mean of 4 replicates)

registered height and number of leaves whose values remained statistically similar to untreated control. Ear heads were produced by *P. minor* only under control treatment and under herbicide application at reduced soil moisture level.

During both the years, susceptible *P. minor* was absolutely controlled with all herbicide treatments. In the present investigation, the reduction in the effectiveness of metribuzin and EC pendimethalin sprayed as pre-emergence was recorded which could be probably due to the fact that these chemicals do not get dissolved easily and hence necessitate the presence of optimal soil moisture conditions for improved efficiency. Early workers also observed inadequate control of weeds under limiting soil moisture conditions with these herbicides (Zanatta *et al*. 2008; Singh 2015). The CS pendimethalin is more concentrated with the active ingredient and has more solubility in comparison to EC formulation (Heinz, 2005). The herbicide molecules are enveloped with a polymer coating in CS formulation. The thickness of the polymer coat is sufficient to check the premature bursting of microcapsules but at the same time allowing the release of pendimethalin. In the spray tank, the microcapsules start priming for release of the active ingredient. This priming aids the formulation to deliver the herbicide molecules in the field for subsequent uptake by the weeds even under low soil moisture conditions. On the other hand, if the soil is dry and EC formulation is being used then there is not sufficient active ingredient dissolved in the soil solution for weed uptake. Therefore, it was found in the present investigation that CS formulation of pendimethalin remained effective equally at both the soil moisture levels.

Phyto-toxicity study

In the present study, all the herbicide treatments were not phyto-toxic to the crop except for metribuzin which exhibited slight phyto-toxic symptoms on wheat at 20 DAS (Table 3). Earlier works have also documented sensitivity of metribuzin on a number of wheat varieties (Gopinath *et al*., 2007; Pandey *et al*., 2006). The growth parameters of wheat under different herbicide treatments sprayed at optimum moisture were at par with those of the unsprayed crop (Table 4). Whereas, the crop grown in 75% of field capacity showed significant reduction in its growth over unsprayed control.

There was a reduction in the efficacy of PRE pendimethalin EC by 52 and 35.5 per cent when applied alone and tank mixed with metribuzin, respectively against resistant population of *P. minor* under limiting soil moisture conditions. While, the CS formulation of pendimethalin provided complete control of *P. minor* irrespective of soil moisture conditions. The formulations tested remained safe to the crop. Further field studies are required to test the efficacy of CS pendimethalin against *P. minor* particularly under dry soil conditions.

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