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Weed management indices as affected by different weed control treatments in pigeon pea [*Cajanus cajan* (L.) Millsp.]

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Abstract
An experiment was conducted to study the efficacy of imidazolinones alone and in combination against weeds in pigeon pea at Agronomy Research Farm, CCS Haryana Agricultural University, Hisar, India having 18 treatment combinations viz.,T_1- Imazethapyr at 75 g ha^{-1} as PRE, T_2- Imazethapyr at 100 g ha^{-1} as PRE, T_3- Imazethapyr at 75 g ha^{-1} at 45 DAS, T_4- Imazethapyr at 100 g ha^{-1} at 45 DAS, T_5- Imazethapyr + imazamox at 70 g ha^{-1} as PRE, T_6- Imazethapyr + imazamox at 100 g ha^{-1} as PRE, T_7- Imazethapyr + imazamox at 70 g ha^{-1} at 45 DAS, T_8- Imazethapyr + imazamox at 100 g ha^{-1} at 45 DAS, T_9- Pendimethalin + imazethapyr at 750 + 50 g ha^{-1} as PRE, T_{10}- Pendimethalin + imazethapyr at 1000 + 50 g ha^{-1} as PRE, T_{11}- Pendimethalin + imazethapyr at 750 + 65 g ha^{-1} as PRE, T_{12}- Pendimethalin + imazethapyr at 1000 + 65 g ha^{-1} as PRE, T_{13}- Pendimethalin + imazethapyr at 750 +75 g ha^{-1} as PRE, T_{14}- Pendimethalin + imazethapyr at 1000 + 75 g ha^{-1} as PRE, T_{15}- Pendimethalin at 1000 g ha^{-1} as PRE, T_{16}- Weed free, T_{17}- Weedy check and T_{18}- Two hoeing at 40 & 70 DAS, replicated thrice in randomized block design during growing seasons of 2017 and 2018.Weed indices were calculated which advocated that all the chemical weed control treatments significantly reduced the weed infestation over weedy check. Treatment T_{13} and T_{14} gave statistically at par grain yield of pigeon pea as in weed free condition which may be due to higher accumulation of growth and yield attributes of pigeon pea due to lower weed-crop competition.

Keywords: Pigeon pea, imazethapyr, pendimethalin, weed indices

Introduction
Food security is must to feed the continuous increasing population but in addition 'nutritional security' has now become an emerging global issue which is haunting the researchers. Pulse crops are commonly known as poor man's meat (Reddy, 2010) [7]. Pulses are considered as the most important food crops after cereals which are not only the major source of dietary protein for vegetarian population of the world but also supply 20 per cent of dietary calories too. In spite of being largest producer, India is lagging behind to produce enough to maintain the pace of population growth and to meet its domestic requirement and has to import two million tonnes of pulses every year by spending huge amount of foreign exchange (Chaturvedi and Ali, 2002) [4]. The per capita availability of pulses has dwindled down from 60 g $capita^{-1}$ day^{-1} in 1951 to 43.0 g $capita^{-1}$ day^{-1} in 2016 as against World Health Organization recommendation of 80 g $capita^{-1}$ day^{-1} (Anonymous, 2018a) [1]. Thus, there is an urgent need to increase the production to meet the increasing demand by improving the production technologies appropriately.

Among pulse crops, pigeon pea [*Cajanus cajan* (L.) Millsp] is one of the most important pulse crops of India after chick pea. It is used for food, feed and fuel. Pigeon pea also known as Arhar, Red gram, Tur, No eye pea, Gungopea and Congopea (Prasad *et al*. 2006) [6] belongs to genus *Cajanus* and species *cajan* under family leguminoceae. It is a good source of rich amino acids (lysine, cysteine, tyrocene and arginine), vitamins (thiamine, riboflavin, choline and niacin) and minerals (iron, calcium, phosphorus, iodine, sulphur and potassium). India has a virtual monopoly in pigeon pea production accounting 67.28 per cent of world's total production from 79.65 per cent of world's total area under pigeon pea. Myanmar, Malawi, Kenya, Tanzania, Haiti and Uganda are the other major pigeon pea producing countries of the world. In India, it occupies an area of 5.34 million hectares and production of 4.87 million tonnes with an average productivity of 913 kg ha^{-1} during 2016-17 (Anonymous, 2018b) [2]. In India, it is grown mainly in Maharashtra, Madhya Pradesh, Karnataka, Uttar Pradesh, Gujarat and Andhra Pradesh. In Haryana, pigeon pea was cultivated over an area of 14.20 thousand hectare with an annual production of 13.0 thousand tonnes and productivity of 915 kg ha^{-1} in 2016-17 (Anonymous, 2018b) [2].

Among various biotic factors limiting pigeon pea yield weeds are of prime importance can causes seed yield losses up to 80% (Talnikar*et al*., 2008) [11]. Rainy season, slow initial growth and sowing at wider spacing of pigeon pea encourage rapid growth and severe infestation of weeds. Hence, initial period of 6-8 weeks of pigeon pea are critical in terms of crop weed competition which may eventually reduce the grain yield (Channappagoudar and Biradar, 2007) [3]. Moreover, besides low yield of crop, weeds increase production cost, hosts insect-pest and diseases, decreases quality of produce, reduce land value leading to reduction in crop production (Subramainian *et al*., 1993) [10]. Hence, weed management is an important key factor for enhancing the productivity of pigeon pea.

Therefore, keeping these in view, the present investigation was carried out to study the efficacy of imidazolinones alone and in combination against weeds in pigeon pea. Further, different weed indices of treatments were calculated as weed indices provide a logistic support in impact assessment, interpretations and drawing appropriate conclusions in weed management research.

Materials and Methods

A field experiment was conducted to study the efficacy of imidazolinones alone and in combination against weeds in pigeon pea at CCS Haryana Agricultural University, Hisar, Haryana, India (29°10'Nlatitude, 75°46'E longitude and 215.2 M altitude) during growing seasons of 2017 and 2018. The experiment was laid out in randomized block design using 18 treatment combinations viz., T_1- Imazethapyr at 75 g ha^{-1} as PRE, T_2- Imazethapyr at 100 g ha^{-1} as PRE, T_3- Imazethapyr at 75 g ha^{-1} at 45 DAS, T_4- Imazethapyr at 100 g ha^{-1} at 45 DAS, T_5- Imazethapyr + imazamox at 70 g ha^{-1} as PRE, T_6- Imazethapyr + imazamox at 100 g ha^{-1} as PRE, T_7- Imazethapyr + imazamox at 70 g ha^{-1} at 45 DAS, T_8- Imazethapyr + imazamox at 100 g ha^{-1} at 45 DAS, T_9- Pendimethalin + imazethapyr at 750 + 50 g ha^{-1} as PRE, T_{10}- Pendimethalin + imazethapyr at 1000 + 50 g ha^{-1} as PRE, T_{11}- Pendimethalin + imazethapyr at 750 + 65 g ha^{-1} as PRE, T_{12}- Pendimethalin + imazethapyr at 1000 + 65 g ha^{-1} as PRE, T_{13}- Pendimethalin + imazethapyr at 750 +75 g ha^{-1} as PRE, T_{14}- Pendimethalin + imazethapyr at 1000 + 75 g ha^{-1} as PRE, T_{15}- Pendimethalin at 1000 g ha^{-1} as PRE, T_{16}- Weed free, T_{17}- Weedy check and T_{18}- Two hoeing at 40 & 70 DAS, replicated thrice. The soil of the field was sandy loam in texture, slightly alkaline in pH (7.8), low in organic carbon (0.48%), poor in available N (217 kg/ ha) and medium in available P (16.7 kg/ha) and rich in available K (278 kg/ha). The pigeon pea variety 'Paras' was raised with standard package of practices. Different weed management indices were calculated to advocate the results as per following formulas:

1. **Weed Control Index (WCI):** worked out taking into consideration the reduction in weed population in treated plot over weed population in unweeded check. It is expressed in %.

$$WCE = \frac{WP_C - WP_T}{WP_C} X\,100$$

Where,
WP_C = Weed population in control (unweeded) plot.
WP_T= Weed population in treated plot.

2. **Weed Control Efficiency (WCE):** worked out taking into consideration the reduction in weed dry weight in treated plot over weed dry weight in unweeded check (control). It is expressed in %.

$$WCI = \frac{W_C - W_T}{W_C} X\,100$$

Where,
W_C = Weed dry weight in control (unweeded) plot.
W_T= Weed dry weight in treated plot.

3. **Weed Index (WI):** Weed index is the measure of the efficiency of a particular treatment when compared with a weed free treatment. It is expressed as percentage of yield potential under weed free. More conveniently weed index is the per cent yield loss caused due to weeds as compared to unweeded (weedy check). Higher weed index mean greater loss. It is worked out by subtracting the yield of treated plot from yield of weed free plot and divided by yield of weed free plot multiply by 100. It is expressed in %.

$$WI = \frac{Y_{WF} - Y_T}{Y_{WF}} X\,100$$

Where,
Y_{WF}= Yield from weed free plot.
Y_T= Yield from treated plot.

4. **Weed Persistence Index (WPI):**

$$WPI = \frac{W_T}{W_C} X \frac{W_{PC}}{W_{PT}}$$

Where,
W_C= Weed dry weight in control (unweeded) plot.
W_T= Weed dry weight in treated plot.
W_{PC} = Weed population in control (unweeded) plot.
W_{PT}= Weed dry weight in treated plot.

5. **Herbicide Efficiency Index (HEI):** indicates the weed killing potential of a herbicide treatment and its phytotoxicity on the crop

$$HEI = \frac{\frac{Y_T - Y_C}{Y_C}}{\frac{W_T}{W_C}}$$

Where,
Y_T = Yield of treated plot.
Y_C= Yield of control (unweeded) plot.
W_C = Weed dry weight in control (unweeded) plot.
W_T= Weed dry weight in treated plot.

6. **Weed Management Index (WMI):**

$$WMI = \frac{\frac{Y_T - Y_C}{Y_C}}{\frac{W_C - W_T}{W_C}}$$

Where,
Y_T = Yield of treated plot.

Y_C= Yield of control (unweeded) plot.
W_C = Weed dry weight in control (unweeded) plot.
W_T= Weed dry weight in treated plot.

7. **Agronomic Management Index (AMI):**

$$AMI = \frac{\frac{Y_T - Y_C}{Y_C} - \frac{W_C - W_T}{W_C}}{\frac{W_C - W_T}{W_C}}$$

Where,
Y_T = Yield of treated plot.
Y_C= Yield of control (unweeded) plot.
W_C = Weed dry weight in control (unweeded) plot.
W_T= Weed dry weight in treated plot.

Results and Discussion

The most dominant weed species found in the experimental site were *Echinochloa colona*, *Cynodon dactylon*, *Digitaria sanguinalis* and *Dactyloctenium aegyptium* among grassy weed; *Trianthema portulacastrum* and *Digera arvensis* among broad-leaf weeds; and *Cyperus rotundus* among sedges.

Table 1 revealed that at 30 days after sowing (DAS), significantly lowest weed density (49.3 m^{-2}) and dry weight (3.1 g m^{-2}) was reported in treatment T_{14} over weedy check where pre-emergence (PRE) application of pendimethalin + imazethapyr at 1000 + 75 g ha^{-1} was done. Similarly at 60 DAS, significantly lowest weed density (64.7 m^{-2}) and dry weight (15 g m^{-2}) were recorded in same treatment T_{14} over weedy check. Because of this low infestation of weed flora in treatment $T_{14,}$ it gave significantly highest grain yield (1,914 kg ha^{-1}) of pigeon pea over rest of the other herbicide treatments except T_{13} to which it was at par. Among different weed control treatments, poor weed management indices was reported with treatment T_{17} (weedy check) due to highest weed infestation. While comparing the herbicide treatments, weed management indices improved with increasing the dose of herbicides used alone or in combination (Table 1).

Table 1: Weed density and weed dry weight as affected by different weed control treatments in pigeon pea (Average of two years)

Treatment	Dose (g ha^{-1})	Time of application	Weed density(No. m^{-2})		Weed dry weight(g m^{-2})		Grain yield (kg ha^{-1})
			30 DAS	60 DAS	30 DAS	60 DAS	
Imazethapyr	75	PRE	10.4 (108.7)	12.3 (152.3)	4.1 (16)	7.4 (54.9)	1,711
Imazethapyr	100	PRE	9.3 (85.3)	11.1 (123.7)	3 (7.9)	5.9 (34.6)	1,776
Imazethapyr	75	45 DAS	19 (360)	18.2 (332)	9.2 (84.1)	10.9 (117.4)	1,434
Imazethapyr	100	45 DAS	19 (360)	16.7 (276.7)	9.3 (85)	9.6 (92.1)	1,538
Imazethapyr + imazamox	70	PRE	11.2 (125.3)	13.1 (170.7)	4.6 (19.8)	8.1 (65.4)	1,654
Imazethapyr + imazamox	100	PRE	10 (100)	11.9 (142)	3.5 (11)	6.5 (41.5)	1,755
Imazethapyr + imazamox	70	45 DAS	18.9 (357.7)	18.2 (330)	9.2 (83.6)	10.5 (110.3)	1,495
Imazethapyr + imazamox	100	45 DAS	18.9 (356.7)	16.4 (267.3)	9.2 (83.1)	9.3 (85.8)	1,589
Pendimethalin + imazethapyr	750+ 50	PRE	9.7 (94.3)	11.1 (122.3)	3.8 (13.8)	6.6 (43.7)	1,760
Pendimethalin + imazethapyr	1000 +50	PRE	8.5 (73)	10.3 (107.3)	3.2 (9.6)	6.4 (40.7)	1,778
Pendimethalin + imazethapyr	750+ 65	PRE	8.4 (69.3)	10 (100)	3.1 (8.5)	5.9 (34.5)	1,828
Pendimethalin + imazethapyr	1000 +65	PRE	7.9 (62.3)	9.4 (88)	2.9 (7.5)	5.4 (28.6)	1,839
Pendimethalin + imazethapyr	750+ 75	PRE	7.4 (54.3)	8.5 (72.3)	2.4 (5.2)	4.8 (22.1)	1,861
Pendimethalin + imazethapyr	1000 +75	PRE	7.1 (49.3)	8.1 (64.7)	2 (3.1)	4 (15)	1,873
Pendimethalin	1000	PRE	13.8 (188.7)	15.7 (247.7)	5.4 (28)	9.1 (82.5)	1,618
Weed free	-	-	1 (0)	1 (0)	1 (0)	1 (0)	1,914
Weedy check	-	-	19 (360)	20.8 (431.7)	9.3 (86.4)	15.1 (230.3)	621
Two hoeing	-	40 & 70 DAS	19.2 (367)	4.4 (18.7)	9.3 (85.5)	1.9 (2.6)	1,890
SEm±			0.35	0.40	0.19	0.43	24
CD at 5%			1.01	1.16	0.54	1.24	70

Original data given in parenthesis were subjected to square root √(x+1) transformation before analysis

Table 2 and 3 shows that at 30 DAS, significantly highest WCI (86.4 %), WCE (96.4 %), HEI (91.0) and significantly lowest WPI (0.23) was observed in treatment T_{14} (PRE application of pendimethalin + imazethapyr at 1000 + 75 g ha^{-1}) which was statistically at par with treatments T_{13} and T_{14} in terms of WCI (85.1 % and 82.9 %, respectively) and WCE (93.9 % and 91.3 %, respectively). Better weed management indices in treatment T_{14} was due to lowest weed infestation. At 30 DAS, WMI and AMI was not significantly affected by different weed control treatment. Highest WMI (2.77) and AMI (1.77) were observed in treatment T_{15} where pendimethalin was applied at 1000 g ha^{-1} as PRE. It may be due to significantly lowest WCE in treatment T_{15} over all other herbicide treatments at 30 DAS.

At 60 DAS, efficiency of different PRE herbicides reduces differently. Herbicides applied at 45 DAS were not much effective in controlling the weeds. At 60 DAS, significant highest WCI (95.6 %) and WCE (98.7 %) was reported in treatment T_{18} where two hoeing at 40 & 60 DAS was done which was statistically at par with T_{12}, T_{13} and T_{14} in terms of WCE. Similar finding were observed by Das *et al*., 2016.While comparing the weed management indices of PRE herbicides, treatment T_{14} gave significantly highest WCI (85.1 %) which was at par withT_{12} and T_{13}; highest WCE (93.2 %) which was significantly superior over T_1 and T_3 (where lower dose of imidazolinones used) and T_9 (pendimethalin + imazethapyr at 750 + 50 g ha^{-1}); significantly highest HEI (34.5) over rest of the other herbicide treatments; and lowest WPI (0.47) which was statistically at par with T_2 and T_6 (where higher dose of imidazolinones used), T_{12} and T_{13}.

Superior weed management indices in T_{14} (pendimethalin + imazethapyr at 1000 + 75 g ha^{-1}) at 60 DAS revealed longer suppression of weed growth by this combination (Table 2 and 3). These results are in collaboration with Singh *et al*., (2018) [8] who also found that highest weed-control efficiency (87.7 %) was recorded with application of imazethapyr + pendimethalin (ready mix) 900 g ha^{-1} and lowest weed index (3.7 %) was recorded in imazethapyr + pendimethalin (ready mix) 800 g/ha in green gram.

Table 2: Effect of different weed control treatment on Weed Control Index (WCI), Weed Control Efficiency (WCE) and Weed Persistence Index (WPI) in pigeon pea (Average of two years)

Treatment	Dose (g ha^{-1})	Time of application	WCI (%)		WCE (%)		WPI	
			30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Imazethapyr	75	PRE	69.9	65.1	80.8	75.8	0.63	0.70
Imazethapyr	100	PRE	76.4	71.6	90.8	84.5	0.40	0.53
Imazethapyr	75	45 DAS	-	23.0	-	46.2	-	0.73
Imazethapyr	100	45 DAS	-	35.7	-	57.1	-	0.67
Imazethapyr + imazamox	70	PRE	65.1	60.1	76.1	69.1	0.70	0.77
Imazethapyr + imazamox	100	PRE	72.4	67.4	86.7	81.4	0.50	0.60
Imazethapyr + imazamox	70	45 DAS	-	23.2	-	47.8	-	0.67
Imazethapyr + imazamox	100	45 DAS	-	37.7	-	61.4	-	0.63
Pendimethalin + imazethapyr	750+ 50	PRE	74.0	71.9	84.3	80.4	0.60	0.73
Pendimethalin + imazethapyr	1000 +50	PRE	80.0	75.4	89.1	81.9	0.53	0.77
Pendimethalin + imazethapyr	750+ 65	PRE	80.8	76.9	90.1	84.1	0.53	0.67
Pendimethalin + imazethapyr	1000 +65	PRE	82.9	79.4	91.3	87.1	0.50	0.63
Pendimethalin + imazethapyr	750+ 75	PRE	85.1	83.5	93.9	90.4	0.43	0.57
Pendimethalin + imazethapyr	1000 +75	PRE	86.4	85.1	96.4	93.2	0.23	0.47
Pendimethalin	1000	PRE	47.2	42.8	65.3	63.7	0.67	0.63
Weed free	-	-	100.0	100.0	100.0	100.0	0.00	0.00
Weedy check	-	-	-	-	-	-	1.00	1.00
Two hoeing	-	40 & 70 DAS	-	95.6	-	98.7	-	0.27
SEm±			1.8	2.2	1.9	4.0	0.05	0.06
CD at 5%			5.2	6.3	5.6	11.7	0.14	0.18

Table 3: Effect of different weed control treatment on Herbicide Efficiency Index (HEI), Weed Management Index (WMI) and Agronomic management Index (AMI) in pigeon pea (Average of two years)

Treatment	Dose (g ha^{-1})	Time of application	HEI		WMI		AMI	
			30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Imazethapyr	75	PRE	10.3	7.8	2.30	2.43	1.30	1.43
Imazethapyr	100	PRE	22.6	12.9	2.17	2.30	1.17	1.30
Imazethapyr	75	45 DAS	-	2.6	-	3.43	-	2.43
Imazethapyr	100	45 DAS	-	3.8	-	2.97	-	1.97
Imazethapyr + imazamox	70	PRE	7.6	6.1	2.37	2.67	1.37	1.67
Imazethapyr + imazamox	100	PRE	15.6	10.7	2.20	2.37	1.20	1.37
Imazethapyr + imazamox	70	45 DAS	-	3.0	-	4.13	-	3.13
Imazethapyr + imazamox	100	45 DAS	-	4.3	-	2.73	-	1.73
Pendimethalin + imazethapyr	750+ 50	PRE	13.4	10.4	2.27	2.40	1.27	1.40
Pendimethalin + imazethapyr	1000 +50	PRE	20.2	11.5	2.20	2.40	1.20	1.40
Pendimethalin + imazethapyr	750+ 65	PRE	23.0	13.6	2.27	2.43	1.27	1.43
Pendimethalin + imazethapyr	1000 +65	PRE	27.5	16.7	2.27	2.37	1.27	1.37
Pendimethalin + imazethapyr	750+ 75	PRE	46.6	22.6	2.23	2.33	1.23	1.33
Pendimethalin + imazethapyr	1000 +75	PRE	91.0	34.5	2.23	2.27	1.23	1.27
Pendimethalin	1000	PRE	5.2	4.8	2.77	2.67	1.77	1.67
Weed free	-	-	-	-	2.17	2.17	1.17	1.17
Weedy check	-	-	-	-	-	-	-	-
Two hoeing	-	40 & 70 DAS	-	-	-	2.13	-	1.13
SEm±			7.8	1.4	0.16	0.47	0.16	0.47
CD at 5%			22.4	4.0	NS	1.36	0.47	NS

Among post-emergence (POE) herbicides treatments (T_3, T_4, T_7 and T_8), T_8 gave significantly highest WCI (37.7 %) and WCE (61.4 %) which was statistically at par with T_4 (Imazethapyr 100 g ha^{-1} at 45 DAS) where higher dose of imidazolinones were used. WPI and HEI are not affected significantly by any of the POE herbicides (Table 3 and 4). Similar results were observed by Singh *et al.*, (2014) [9].

WMI and AMI are inversely proportion to WCE and increase in yield. Lowest value of WMI and AMI depict higher WCE or/and comparatively higher addition of yield occurs due to effect of treatment whereas, higher the WMI or AMI means lower its WCE or/and comparatively lower addition of yield occurs due to effect of treatment. Similar as 30 DAS, WMI and AMI at 60 DAS were not affected significantly by any of the weed control treatment. Highest WMI (4.13) and AMI (3.13) were recorded in treatment T_7 which was due to lower WCE (Table 3).

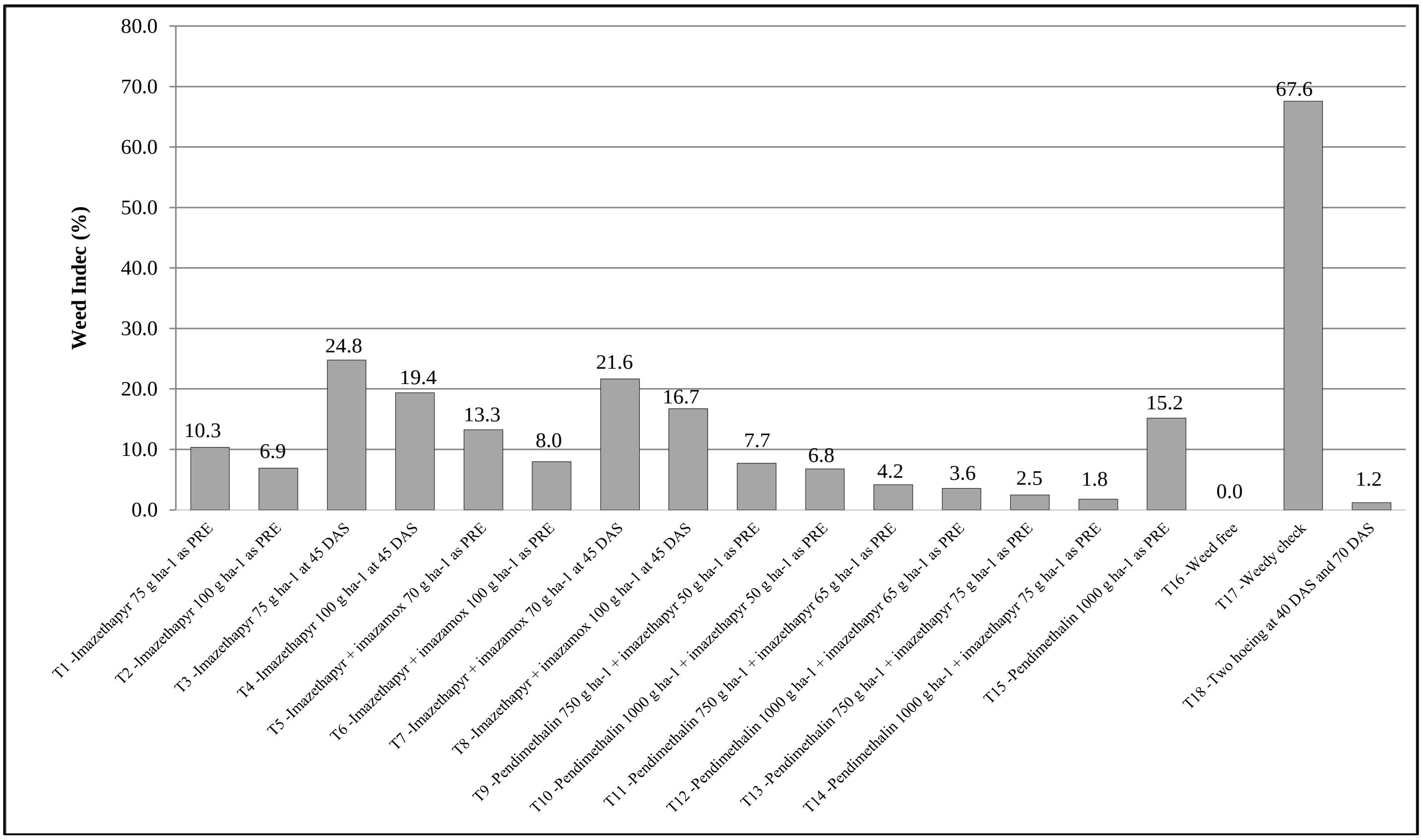

Fig 1: Effect of different weed control treatments on weed index (%) in pigeon pea (Avg. of two years)

Fig. 1 depict the weed index of different weed control treatments in pigeon pea revealed that if weeds are allowed to grow freely it can causes the yield losses in pigeon pea up to 67.6 per cent. Best treatment in terms of weed index was T_{16} (weed free) which was closely followed by T_{18}, T_{14}, T_{13} and T_{12}.

Conclusion

Grain yield of pigeon pea can be reduces up to 67.6% due to weed infestation. In pigeon pea, weed ca n be effectively managed by pre-emergence application of imidazolinones alone and in combination with pendimethalin and weed indices in pigeon pea can be effectively improved by increasing the dose of herbicides used alone or in combination in experiment. However, finding shows that among different herbicides treatments, treatment T_{14} and T_{13} gave better results in terms of weed management indices and yield of pigeon pea. Therefore, pre-emergence application of pendimethalin + imazethapyr at 1000 + 75 g ha^{-1}(T_{14}) and 750 + 75 g ha^{-1} (T_{13}) proved to be an effective and a profitable alternative to the existing recommendation of weed control (two hoeing at 25 and 45 DAS) for pigeon pea in Haryana locality.

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