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Research Article
Efficacy of Oxyfluorfen Herbicide for Weed Control In Broccoli (*Brassica oleracea* L. var. *italica*)

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Abstract

Background and Objective: Increased demand for fresh market head broccoli (*Brassica oleracea* L. var. *italica*) has led increased production in area Batu, Indonesia. Weeds are a major problem in broccoli cultivation. There are still limited information to prevent the yield loss caused by weeds, therefore the herbicide application in broccoli growth were researched. The objective of this study was to determine the effect of several weed control managements to obtain the most effective and efficient weed control in broccoli. **Methodology:** The research was conducted in Temas Village, Batu Sub-District, East Java (900 m a.s.l) during rainy season, since February until May 2016. This study established using Randomized Block Design consisting of seven treatments with four replications and comprised seven methods of weed control viz: Wy (weedy), Wf (weed free), W15 (weeding at 15 DAT), W15 +30 (weeding at 15 and 30 DAT), O1 + W15 (oxyfluorfen 240 g a.i ha^{-1} + weeding at 15 DAT), O1.5 (oxyfluorfen 360 g a.i ha^{-1}) and O2 (oxyfluorfen 480 g a.i ha^{-1}). Data obtained were subjected to an one-way analysis of variance (ANOVA) at 0.05 level, if there is a significance difference will be continued by Fisher's Least Significant Differences (LSD) test at the 0.05 probability level. **Results:** The results of this study showed that treatment methods of weed controls on were significant difference ($LSD_{0.05}$) between weed dry weight and the growth parameters of broccoli such as: plant height, leaf area, fresh weight of head, head diameter, fresh plant weight and yield (t ha^{-1}). Based on Sum Dominance Ratio (SDR) analysis, the dominant weeds found were *Eleusine indica* and *Portulaca oleracea* (grasses). The Weed Control Effeciency (WCE) indicated that O2 treatment (oxyfluorfen 480 g a.i ha^{-1}) was effective and efficient in controlling weeds such as *Portulaca oleracea* and *Amaranthus blitum* in the broccoli. **Conclusion:** The oxyfluorfen 480 g a.i ha^{-1} as a recommended treatment, this treatment significantly reduced ($LSD_{0.05}$) weed dry weight 92.36% until 56 DAT and was not caused injury to the broccoli. By using this treatment, could produce 15.18 t ha^{-1} of broccoli head and no significant different from Wf (weed free) treatment.

Key words: *Brassica oleracea* L. var. *italica*, broccoli, herbicide, oxyfluorfen, weed control

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Broccoli (*Brassica oleracea* L. var *italica*), is one type of vegetables of horticultural commodities that are highly consumed by people and has a high economic value. In 2015, the production of broccoli in Indonesia reached approximately 113.9 t year^{-1}. Moreover, broccoli demand increases between 20-30% every year for both national and international needs. Therefore, it is essential to pay attention on the cultivation of broccoli plants[1].

In the cultivation of broccoli, the presence of weeds could reduce yields and increase maintenance costs. Interference between weeds and plants are caused by the competition of nutrients, light and water. On the other hand, weeds are also capable of hosting pests and diseases[2]. Therefore, weed control needs to be conducted to suppress the growth and the increasing number of weeds. Some researchers have reported losses of yield caused by weeds. Qasem[3] discussed weed competition in cauliflower (*Brassica oleracea* L. var. *botrytis*) in the Jordan Valley which indicated that the presence of weeds could drastically decrease the shoot dry weight and head weight by 81 and 89%, respectively, whereas weed competition at 14 DAT (days after transplanting) could lower the head weight by 41%. Suwitnyo *et al.*[4], found that the competition of *Altenanthera sessilis* (135 m^{-2}) reduced the total dry weight of cauliflower plant by as many as 46.85% compared to the treatment without weed competition, while the existence of weeds on canola (*Brassica napus* L.) decreased seed production by 84.34%[5].

Furthermore, weed control methods in the field depend on several factors, such as: crop variety, stage of crop growth, weed species, labor and cost availability[6]. Obviously, manual weeding takes a long time and requires more workers. Besides, this method needs to be done intensively because weeds can regrowth quickly. To fulfil the lack, oxyfluorfen herbicides is introduced as an alternative chemical control for the cost efficiency on the weed control. Bhowmik and McGlew[7] proposed that oxyfluorfen (480 g a.i kg ha^{-1}) on pretransplant applications could control grasses by 86-89% and were effective to control broadleaf weeds in the cultivation of cabbage. Additionally, the application of oxyfluorfen (480 g a.i kg ha^{-1}) in pretransplant treatment was the best way in controlling weeds up to 65.5% compared to the unweeded treatment, without affecting growth and yield[8].

However, information on weed controls in broccoli cultivation available in Indonesia is still limited, especially the application of oxyfluorfen. Thus, this study aimed to determine the effectiveness of variant weed controls and the effect on the growth and yield of broccoli.

MATERIALS AND METHODS

This experiment was conducted in Temas Village, Batu, East Java located 900 m a.s.l. during the rainy season, since February until May 2016. The experiment were established using Randomized Block Design (RBD) with four replications and comprised seven methods of weed control viz: Wy (weedy/unweeded), Wf (weed free), W15 (weeding 15 DAT), W15+30 (weeding 15 and 30 DAT), O1+W15 (oxyfluorfen 240 g a.i ha^{-1} + weeding 15 DAT), O1.5 (oxyfluorfen 360 g a.i ha^{-1}) and O2 (oxyfluorfen 480 g a.i ha^{-1}). This experiment included two type of control viz: Weedy (Wy) was neither treated with herbicide nor weeded and weed free (Wf), was weeded mechanically at interval two weeks until harvest.

The broccoli seedling F1 Green Magic variety (3-4 leaf stage) were planted manually with 40×40 cm plant spacing. The size of experimental plot was 13.44 m^{-2} (2.8×4.8 m), so the total area was 483.4 m^2. Each treatment consisted of 84 seedlings.

Application of oxyfluorfen (Goal 2E) was done using pretransplant with 500 L water ha^{-1} (herbicide was applied as an aqueous spray at a constant pressure). Herbicide treatments were applied 2 days before transplanting using a knapsack sprayer "SOLO" with flat fan nozzle. The weeds were identified and counted using three (80×80 cm) systematically places in the treated and untreated of halve each plot. The observations were done on the 14, 28, 42, 56 DAT. Observation data included Summed Dominance Ratio (SDR) and Weed Control Efficiency (WCE).

Summed Dominance Ratio (SDR) of the weed species was computed using the following equations[9].

$$\text{SDR (\%)} = \frac{(\text{RD}+\text{RI}+\text{RF})}{3} \quad (1)$$

$$\text{RD (\%)} = \frac{\text{Density of certain species}}{\text{Density of all species in plots}} \times 100 \quad (2)$$

$$\text{RI (\%)} = \frac{\text{Coverage of certain species}}{\text{Coverage of all species in plots}} \times 100 \quad (3)$$

$$\text{RF (\%)} = \frac{\text{Number of plots in which certain species appear}}{\text{Number of plots in which all species appear}} \times 100 \quad (4)$$

Weed Control Efficiency (WCE) was calculated using Eq. 5[10].

$$\text{WCE (\%)} = \frac{\text{WD}_c - \text{WD}_t}{\text{WD}_c} \times 100 \quad (5)$$

Where:
WCE = Weed control efficiency (%)
WD_c = Weed biomass (g 0.64 m^{-2}) in the weedy plot
WD_t = Weed biomass (g 0.64 m^{-2}) in the treated plot

A crop injury observation due to herbicide application was rated on a scale of 0-100% in 7 Days After Transplanting (DAT). A rating of 0% was de ned as no visible effect of the herbicide and 100% was de ned as plant death. Observations of plant growth involved the plant height and leaf area. Yield observations were done on the fresh head weight, head diameter, fresh plant weight and yield.

Statistical analysis: Data on broccoli and weed growth were recorded and subjected to one way analysis of variance (ANOVA), if there is a significance difference will be continued by Fisher's Least Significant Differences (LSD) test at the 0.05 probability[11].

RESULTS AND DISCUSSION

Effect on weeds: Table 1 shows that 56 DAT observations on Wy (weedy) treatment contained 10 weeds species, consisting of broadleaf weeds, grasses and sedges. The existing weeds included *Eleusine indica* (SDR = 35.50%), *Portulaca oleracea* (SDR = 16.09%), *Echinocloa colona* (SDR = 13.07%), *Amaranthus blitum* (SDR = 12.36%), *Emilia sonchifolia* (SDR = 8.82%), *Prunella vulgaris* (SDR = 7.04%), *Bidens pilosa* (SDR = 5.75%), *Cyperus rotundus* (SDR = 5.32%), *Ageratum conyzoides* (SDR = 2.87%) and *Sesbania grandiflora* (SDR = 1.61%). The data showed that *Eleusine indica* and *Portulaca oleracea* dominated the experimental plot. Application of oxyfluorfen 360 and 480 g a.i ha^{-1} effectively suppressed of *Portulaca oleracea* and *Amaranthus blitum* until the observation periods of 42 and 56 DAT, if compared with Wy (weedy) treatment. However, species *Ageratum conyzoides*, *Emilia sonchifolia* (broad leaf weeds), *Eleusine indica* and *Echinocloa colona* (grasses) still dominance at the experiment plots. It showed that with oxyfluorfen up to a dose of 480 g a.i ha^{-1} oxyfluorfen was unable to control two species of grasses. However, the study of Osman *et al.*[12], showed that oxyfluorfen at rate of 0.21, 0.28 and 0.35 kg a.i ha^{-1} is excellent control (81-100%) of annual grasses, especially *Echinocloa colona* and broadleaf weeds at early season. Ramalingam *et al.*[13] stated that broadleaf weeds could effectively be controlled by oxyfluorfen herbicides. Similarly, the results of Karkanis *et al.*[14] and Vasic *et al.*[15] showed that oxyfluorfen had the best control of

Table 1: SDR (%) observation on each treatment on various weed controls

	Treatments															
	Wy		Wf*		W15		W15+30		O1+W15		O1.5		O2			
Species	42 DAT	56 DAT	42 DAT	56 DAT	42 DAT	56 DAT	42 DAT	56 DAT	42 DAT	56 DAT	42 DAT	56 DAT	42 DAT	56 DAT		
Eleusine indica	39.59	37.5	-	-	21.64	24.48	44.09	22.82	47.82	42.84	23.09	41.02	47.321	34.03		
Cyperus rotundus	5.8	5.32	-	-	7.23	5.96	-	10.48	4.45	5.66	19.26	9.21	-	3.06		
Portulaca oleracea	15.21	16.09	-	-	4.87	5.06	11.09	13.93	3.85	6.35	-	-	4.71	7.32		
Prunella vulgaris	-	7.04	-	-	-	-	-	-	-	-	-	-	-	-		
Ageratum conyzoides	4.3	2.87	-	-	7.23	3.36	-	4.28	5.49	4.94	11.78	6.36	12.25	15.5		
Amaranthus blitum	10.07	12.36	-	-	10.55	12.57	6.5	11.05	7.07	9.17	10.56	8.86	3.52	-		
Difitaria ciliaris	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-		
Sesbania grandiflora	-	3.58	-	-	-	-	-	-	-	-	3.52	-	1.17	-		
Echinocloa colona	14.16	13.07	-	-	7.97	9.48	-	16.46	14.12	9.26	16	9.92	19.8	19.18		
Panicum dichotomiflorum	3.62	-	-	-	30.18	21.25	28.69	11.95	8.09	9.04	7.15	13.56	2.38	-		
Euphorbia hirta	-	-	-	-	-	5.31	-	-	-	-	-	-	-	-		
Amaranthus spinosus	-	-	-	-	3.55	3.91	9.62	5.52	-	1.83	-	-	-	-		
Bidens pilosa L.	5.65	5.75	-	-	3.61	3.35	-	-	1.56	4.64	2.69	4.15	-	6.56		
Emilia sonchifolia	4.99	8.82	-	-	3.16	2.28	-	-	7.56	6.27	5.94	6.96	15.92	14.35		
Galinsoga parviflora	-	-	-	-	-	-	-	3.51	-	-	-	-	-	-		

*Not observed, DAT: Days after transplanting

Table 2: Weed dry weight and Weed Control Efficiency (WCE) on various weed controls

	Weed dry weight (g 0.64 m^{-2})			WCE (%)		
	Observation periods (DAT)			Observation periods (DAT)		
Treatments	28*	42	56	28	42	56
Wy	102.52^{d}	171.48^{e}	120.65^{d}	-	-	-
Wf	5.85^{bc}	6.93^{a}	5.10^{a}	94.29	95.96	95.77
W15	9.53^{c}	116.83^{d}	92.40^{c}	90.70	31.87	23.41
W15+30	11.43^{c}	21.65^{ab}	2.28^{a}	88.85	87.37	98.11
O1+W15	2.30^{ab}	78.50^{c}	56.18^{b}	97.76	54.22	53.44
O1.5	1.38^{a}	45.65^{b}	4.43^{a}	98.65	73.38	96.33
O2	0.83^{a}	13.10^{a}	2.40^{a}	99.19	92.36	98.01
LSD (5%)		14.54	31.7			
CV (%)		24.18	32.55			

Means followed by the same letter at the same column showed no significant difference based on LSD test at level 5%, DAT: Day after transplanting, *Data has been transformed to √(X+0.5) where X is original data

Table 3: Plant height of broccoli on various weed controls

	Plant height (cm) on observation periods (DAT)		
Treatments	28	42	56
Wy	16.69	29.69^{a}	37.38^{a}
Wf	21.56	35.38^{bc}	50.38^{bcd}
W15	19.31	30.13^{ab}	44.50^{ab}
W15+30	20.13	34.38^{abc}	53.63^{cd}
O1+W15	20.56	32.56^{ab}	46.75^{bc}
O1.5	20.94	34.25^{abc}	47.38^{bc}
O2	23.31	39.38^{c}	56.00^{d}
LSD (5%)	NS	5.65	8.45
CV (%)	18.84	11.29	11.85

Means followed by the same letter at the same column showed no significant difference based on LSD test at level 5%, DAT: Day after transplanting, NS: Non significant

broad leaf weed viz: *Amaranthus retroflexus* L., *Convolvulus arvensis* L., *Datura stramonium* L. and *Portulaca oleracea* L.

Weed control significantly affected the weed dry weight, both manually and by herbicide treatment. Table 2 shows an increase in the weed dry weight at each age. The weed dry weight decreased due to the weed control treatment since the observation in the 28-56 DAT. In the 56 DAT observation, the most significant reduction on the weed dry weight was showed by treatment W15+30 (weeding 15 and 30 DAT), O1.5 (oxyfluorfen 360 g a.i ha^{-1}) and O2 (oxyfluorfen 480 g a.i ha^{-1}) by 8.11, 96.33 and 98.10% compared to the Wy (weedy). Whereas, W15 (weeding 15 DAT) and O1+15 (oxyfluorfen 240 g a.i ha^{-1} + weeding 15 DAT) showed a lower reduction on the weed dry weight than the three treatments above.

Weed Control Effeciency (WCE) value indicated the weed dry weight using treatment of weed control compared to the treatment without weeding (Wy). The WCE value was declining closer to the harvest time (Table 2). It was caused by the growth of certain weed species that are resistant to weed control treatments. The WCE value depends on the effectiveness of weed control techniques used as with the treatment of W15 + 30, the application of oxyfluorfen 360 and 480 g a.i ha^{-1}. Ramalingam *et al.*[13], stated that an increase in oxyfluorfen dose of 150-480 g a.i ha^{-1} increased the WCE by 80.38-95% in 20 days after sowing and 70-89.40% in 40 days after sowing in the onion cultivation. A strong positive correlation of weeding treatments was also found by Amare *et al.*[16], who recommended the use of herbicides is more effective in reducing the weed density and weights than the manual weeding treatment. Similarly, the result of Qasem[8] research showed that the use of oxyfluorfen (pretransplant) has a very good effect on suppressing weeds, which is indicated by the decrease of weed dry weight by 65.50% compared to the control. Weed suppression at the beginning of plant growth will be very useful to have no competition between weeds and plants during critical periods because the presence of weeds negatively affects the growth and yield[2].

Effect on growth and yield of broccoli: There was no toxicity on broccoli as a result of pretranspant application at each dose of oxyfluorfen (240 and 360 g a.i ha^{-1}). The study of Reis *et al.*[17], showed that oxyfluorfen 240 g a.i ha^{-1} applied before and after transplant did not affect the number of productive and suppressed plants nor yield being selective in cabbage. Sikkema *et al.*[18] showed that pretransplant oxyfluorfen at 560 and 1120 g a.i ha^{-1} doses were not toxic to broccoli and had no effect on the broccoli yield. The tolerance of broccoli to oxyfluorfen herbicides is caused by the pretransplant already formed in the deeper roots on broccoli seedlings that are planted in the soil[19].

The effect of weed control on plant height occurs at ages 42 and 56 DAT. Table 3 shows that Wy (weedy) can lower the height of broccoli about 16.08% (42 DAT) and 25.80% (52 DAT)

compared to Wf (weed free), where as W15+30 (weeding 15 and 30 DAT) and O2 (oxyfluorfen 480 g a.i ha^{-1}) showed no significant difference than Wf (weed free).

The effect of weed control on the leaf area of broccoli had occurred since the 28-56 DAT, Table 4 shows that Wy (weedy/unweeded) can decrease the leaf area of broccoli about 38.45% (28 DAT), 36.17% (42 DAT) and 58.25% (52 DAT) compared to Wf (weed free), where as the results of W15+30 (weeding on 15 and 30 DAT), O1.5 (oxyfluorfen 360 and 480 g a.i ha^{-1}), were not significantly different from Wf (weed-free) treatment. The absence of the difference between the three treatments on the plant height and broccoli leaf area compared to the treatment of Wf (weed free) indicates that the treatment is able to suppress weed growth significantly, as indicated in WCE (Table 2). Each treatments can suppress the weed dry weight by 87.37-99.11% compared to the Wy (weedy) treatment.

Qasem[3] showed in his research that treatment oxyfluorfen at 600 g a.i ha^{-1} at pretransplant application is the most effective and selective treatment in weed control because it could eliminate weed, so that it can ultimately increase the plant growth and yield. Pannacci and Tei[20] stated that hand weeding can ensure selectivity to plants. Nevertheless, weed management also should be done effectively and efficiently.

Table 5 shows that weed control treatments had a significant effect on the yield parameter of broccoli, such as: brocolli head diameter, fresh head weight, fresh plant weight and yield.Weedy (Wy) treatment could reduce the head diameter, fresh head weight, fresh plant weight and yield by 31.58, 60.16, 33.26 and 60.19% compared to Wf (weed free). Treatment {(W15+30 (weeding 15 + 30 DAT) and O2 (oxyfluorfen 480 g a.i ha^{-1})} had a positive result, but there was no significant difference on the head diameter, fresh head weight, fresh plant weight and yield of t ha^{-1} compared with Wf (weed free), where both up to 56 DAT observations showed WCE values of 98.11 and 92%, respectively.

Head of broccoli on W15+30 was 14.56 t ha^{-1}, O2 treatment was 15.18 t ha^{-1}, but both treatment showed no significant difference from Wf (weed free). This means that an effective and efficient weed control option for broccoli was using application of oxyfluorfen 480 g a.i ha^{-1}, although W15 + 30 treatment was also not significantly different from weed free (Wf) treatment. However, considering the labor requirements for hand weeding is high, then weed free treatment is not recommended. By using chemical is a better alternative because it is cheaper in price, labor saving and fast and better than manual weeding[12,16,19].

Oxyfluorfen (560 and 1120 g a.i ha^{-1}) as a pretransplant application has been shown effective to control broadleaf weeds and annual grasses in broccoli, cauliflower and cabbage plants, without causing any visual injure, not reducing the number of broccoli heads and the head weight that is produced[13]. Similarly, Bhowmik and McGlew[7], reported that oxyfluorfen as a pretransplant application gave 86 and 89% control of grass species and broadleaf weeds were controlled effectively. Cabbage had acceptable tolerance to oxyfluorfen (430 and 560 g a.i ha^{-1}). Yield and quality of cabbage were not reduced by the application of oxyfluorfen. Yields of marketable cabbage were obtained with the treatment of oxyfluorfen as pretransplant application.

Table 4: Leaf area on various weed controls

	Leaf area (cm^2 per plant) on observation periods (DAT)		
Treatments	28	42	56
Wy	22.82^{a}	71.20^{a}	75.84^{a}
Wf	37.08^{b}	111.56^{cd}	181.82^{bc}
W15	37.90^{b}	86.51^{ab}	124.18^{ab}
W15+30	43.11^{b}	120.56^{d}	215.94^{c}
O1+W15	32.09^{ab}	92.98^{bc}	154.51^{b}
O1.5	32.58^{ab}	106.77^{bcd}	180.10^{bc}
O2	54.46^{c}	122.13^{d}	217.97^{c}
LSD (5%)	11.03	20.8	59.93
CV (%)	20.00	13.49	24.55

Means followed by the same letter at the same column showed no significant difference based on LSD test at level 5%

Table 5: Yield parameters of broccoli on various weed controls at harvest

Treatments	Head diameter (cm)	Fresh weight (g per head)	Total fresh weight (g per plant)	Yield (t ha^{-1})
Wy	7.17^{a}	127.47^{a}	582.18^{a}	6.13^{a}
Wf	10.48^{d}	319.96^{d}	872.38^{bc}	15.40^{d}
W15	7.96^{ab}	169.94^{b}	548.42^{a}	8.18^{b}
W15+30	10.29^{cd}	302.61^{d}	907.35^{c}	14.56^{d}
O1+W15	7.38^{a}	197.47^{b}	709.08^{ab}	9.50^{b}
O1.5	8.92^{bc}	240.49^{c}	866.29^{bc}	11.57^{c}
O2	10.83^{d}	315.47^{d}	896.64^{c}	15.18^{d}
LSD (5%)	1.52	35.99	172.05	1.73
CV (%)	11.35	10.13	15.06	10.13

Means followed by the same letter at the same column showed no significant difference based on LSD test at level 5%

Growth component should determine how the results are obtained. If the growth period is disrupted, it will decrease the crops yield. The presence of weeds on agricultural land can also decrease yields, as well as reduce the yield quality[21]. Raoofi *et al.*[22] stated that the lower biomass and weed density in the garlic experimental plot increased the yield and high economic results.

CONCLUSION

Application of oxyfluorfen herbicide 480 g a.i ha^{-1} on pretransplant was effective and efficient to control weeds in broccoli cultivation because this treatment was able to suppress weed growth up to 92.36%, control broadleaf weeds up to 56 DAT and was not caused injury to the broccoli. This treatment could produce 15.18 t ha^{-1} broccoli head and it was not significantly different from Wf (weed free) treatment.

SIGNIFICANCE STATEMENTS

This study discovers the possibilities of oxyfluorfen herbicide to control weeds in the broccoli cultivation area by effective and efficiently, that can be beneficial for the optimum broccoli yield. This study will help the researcher to uncover the critical areas of application doses of oxyfluorfen, that many researchers were not able to explore. Thus a new theory on oxyfluorfen and possibly other active ingridient on herbicide may be arrived at.

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