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Integrated management of problematic weed corn marigold in wheat fields at West and South West Shewa Zones in Ethiopia

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Abstract: Background: Corn marigold (*Glebionis segetum*) is a serious weed of cereal and pulse crops in many parts of Ethiopia. However, there is a lack of information on its management in wheat fields in the country.
Objective: The current work was designed with the objectives of evaluating integrated management of the weed and determining the most economical integrated weed management options in wheat fields.
Methods: The field experiments were conducted in naturally corn marigold infested fields in the Cheliya and Woliso districts of Western and Southwestern Ethiopia, respectively, during 2020 to 2021 cropping seasons using a randomized complete block design with three replications. The treatments were 1) Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} + hand weeding, 2) Pyroxsulam 45 g L^{-1} + hand weeding, 3) Flurasulam 75 g L^{-1} + Flumetsulam 100 g L^{-1} + hand weeding, 4) twice hand weeding 5) weed free, and 6) weedy check.
Results: Different corn marigold management practices resulted in different responses to all measured for the crop and weed parameters. Application of Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} at a rate of 50 g ha^{-1} supplemented with a single hand weeding and Pyroxsulam 45 g L^{-1} sprayed at a rate of 0.50 L ha^{-1} supplemented with a single hand weeding increased grain yield by 87 and 74%, respectively, as compared to the weedy check. The marginal revenue and benefit-cost ratio obtained from the marketing of goods for the application of Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} with a single supplementary hand weeding of corn marigold increased by about 149% and 165%, respectively, as compared to the weedy check.
Conclusions: The present study revealed the role of integrated management of corn marigold in improving wheat production and productivity. Future research should be directed towards scaling up and expanding these technologies among growers.

Keywords: Effective Management; *Glebionis Segetum*; Golden Flower; Integrated Management; Marginal Revenue

1. Introduction

With an annual global production of 772.6 million tons, bread wheat is a staple food for more than 35% of the world's population (Nigus et al., 2022). The largest producers of wheat worldwide are China, India, and Russia, whereas South Africa and Ethiopia are the largest producers in sub-Saharan Africa (Paulsen et al., 2012). After tef and maize, wheat ranks third in importance among cereal crops in Ethiopia with a share of 17% of the country's total grain production (Gizaw, Assegid, 2021).

However, in Ethiopia annual production of wheat is approximately 5.8 million tons, with a mean productivity of 3 tons per hectare (Silva et al., 2021; CSA 2021), which is significantly lower than the crop's attainable yield of up to 5 tons per hectare (Zegeye et al., 2020). Wheat production and productivity are affected by complex and interactive effects of biotic and abiotic factors and socio-economic challenges, notably in the smallholder farming systems (Krupnik et al., 2021).

Weeds are one of the most critical biotic factors affecting wheat production and productivity. They infest wheat fields and have the potential to reduce yield and crop quality. Corn marigold (*Glebionis segetum* (L.) Fourr.) is one of the alien weed species causing threats to crop production in many countries in the world. The genus name of the weed (Chrysanthemum) was originally derived from the Greek words chrusos, "gold," and anthemon, "flower" (golden flower), but was later altered to Glebionis (Nougarede, 2019).

Corn marigold is native to Eastern Mediterranean and North Africa (Nougarede, 2019) and later introduced and spread to many countries including Ethiopia (Shashitu et al., 2018). It was introduced into Ethiopia with contaminated grain food aid during famine of 1985 (Shashitu, 2019). Since then, it has spread from infected areas to uninfected areas by animal dung, flooding, crop seed, birds and farm machineries (Shashitu, 2019). It is a noxious weed whose management is difficult due to its prolific seed production, rapid growth and spreading ability, adaptation to a wide range of nutrient and environmental conditions, and strong competitiveness with crops. It has complex root system which is not easily uprooted and cutting aggravates its infestation. It is known for its many branches and golden flowers (Figure 2A-B).

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Corn marigold is a serious weed species on barley and wheat crops in Dabat (Assefa, 2019), Debark districts (Asres, Das, 2011) in Amhara regional state and in Cheliya and Woliso Districts (Shashitu, 2019) in Oromia regional state in Ethiopia. It is becoming a serious weed in crop production and causes yield and seed quality reduction in

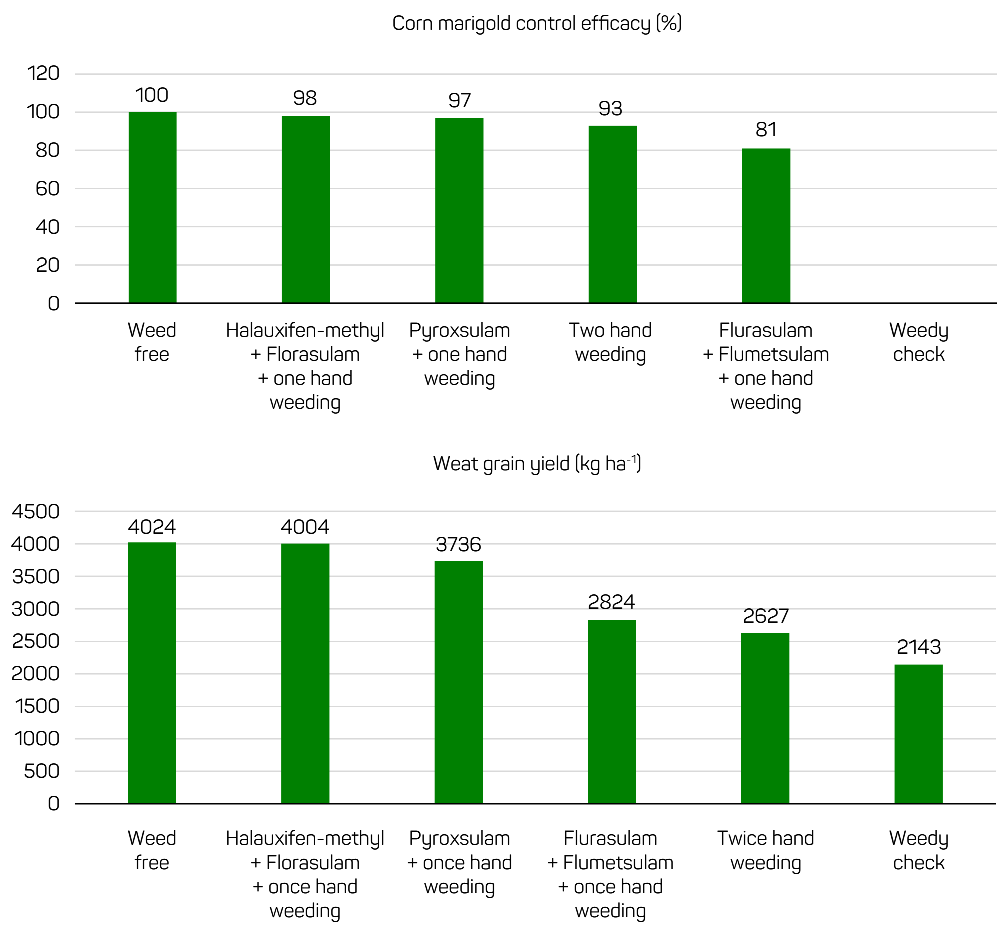

Figure 1 - Graphical representation of corn marigold management control

Figure 2 - Corn marigold with its A) many branches B) golden flowers

crops in highland parts of the country. The weed has been reported to cause 56% yield losses in wheat in Ethiopia if appropriate management measures are not implemented (Shashitu et al., 2018).

In the aforementioned areas, the weed was observed to be spreading fast and invading crop lands at an alarming rate. It is the most important weed species having negative impacts on crop production followed by *Snowdina polstachiya, Raphanus rafanistrum,* and *Gizotia scabra* at Cheliya and Woliso (Shashitu, 2019). It infests faba bean, field pea, wheat, and wheat fields in Cheliya and Woliso districts in Oromia regional state in Ethiopia (Figure 3A-D).

Cultural and chemical control methods are the commonly used weed management methods in wheat fields to reduce the negative impact of corn marigold. Family labor is insufficient during the main cropping season for timely and adequate management of corn marigold in wheat fields due to overlapping operations with other crops. Hand-weeding wheat fields is time-consuming and usually done late in the season, after the weeds have reduced crop plant growth. Hand-weeding is especially difficult because of the heavy rainfall during the main cropping season, which prevents going into the field and conducting field activities.

In wheat, the herbicides Aminopyralid + Florasulam at 30 g ha^{-1} and Pyroxsulam 45g L^{-1} at 0.5 liters ha^{-1} were recommended for corn marigold (Shashitu et al., 2018). However, wheat growers complained that application of the herbicides alone unlikely offer a long-lasting solution to the serious problem of this weed in wheat fields.

Therefore, this study was conducted with the objectives of developing effective integrated management of corn marigold, determining the grain yield benefit, and determining the most economical integrated weed management options in wheat production in the selected sites of the West and Southwest Shewa Zones of Ethiopia.

2. Materials and Methods

2.1 Study area

The study was conducted at Cheliya and Woliso districts in Oromia regional state in farmers' fields during June to December cropping seasons of 2020 and 2021. One naturally corn marigold infested field per district was selected (Table 1 and Figure 4).

2.2 Treatments, experimental design and crop husbandry

The experiment was arranged in randomized complete block design with three replications. The experimental treatments included 1) Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} + hand weeding, 2) Pyroxsulam 45 g L^{-1} + hand weeding, 3) Flurasulam 75 g L^{-1} + Flumetsulam 100 g L^{-1} + hand weeding, 5) twice hand weeding (farmers practice) 5) weed free, and 6) weedy check (Table 2). The experimental plot size was 4 m x 5 m. Spacing 1.5 m between

Figure 3 - Pictures of corn marigold in A) Field pea, B) Faba bean; C) Wheat, D) Tef

Table 1 - Description of the study area

Zone	District	Specific place	Altitude	Latitude	Longitude
West Shewa	Cheliya	Chobi Tulu	2488	9.03049	37.45348
Southwest Shewa	Woliso	Adami Gotu	2304	8.62010	38.02782

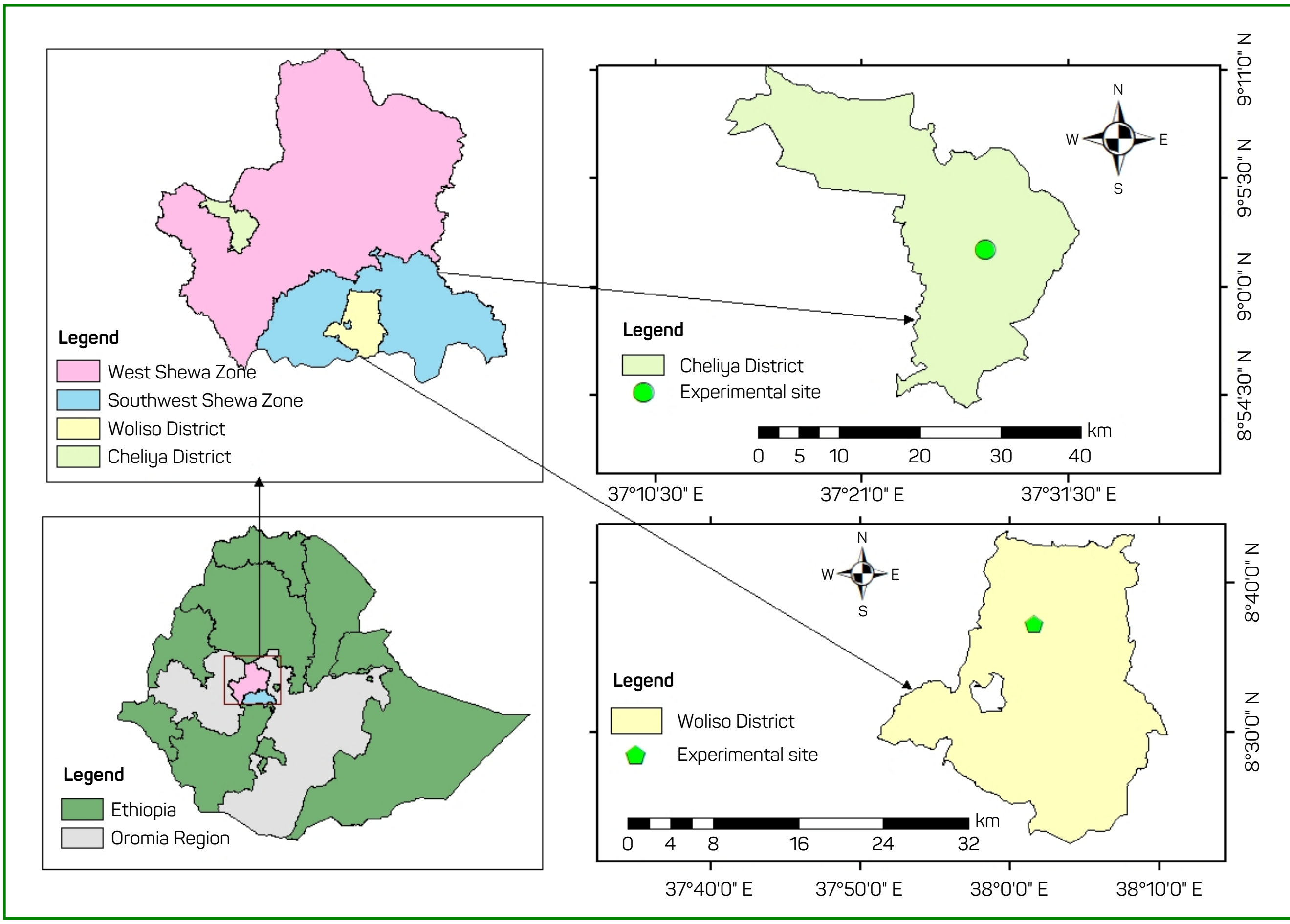

Figure 4 - Map of Ethiopia showing regions, zones and districts at which the experiments were conducted

blocks and 1 m between plots were used. Bread wheat 'Wane' Varity at 150 kg ha^{-1} was drilled in rows of 25 cm apart. Diammonium phosphate (DAP) and urea fertilizers were applied at rates of 200 and 150 kg ha^{-1}, respectively. DAP was applied at sowing time, whereas urea was applied in two applications with half at sowing time and half at the tillering stage of the crops. The recommended rates of herbicides were applied 30 Days after seed sowing (DAS) and the supplementary hand weeding were conducted 60 DAS as a components of integrated weed management (Table 2). For all herbicide treatments, a uniform water volume of 200 L ha^{-1} was used to make spray solusion.

2.3 Data collected

Corn marigold parameters such as the number of corn marigolds before and after treatment, biomass and visual scoring were recorded. Weed control efficacy was calculated using the formula indicated below (Equation 1). Bread wheat parameters such as total number of tillers, number of productive tillers, plant height, spike length, number of seeds per spike, biomass and grain yield were recorded, and harvest index were calculated. The number of corn marigold were counted at 30 and 60 DAS using 1 m * 1 m quadrat three times per plot. Visual scoring was undertaken using 1–5 scale scoring system at 15 and 30, days after herbicide application (Taye et al., 2007). Where 1 = no herbicide symptoms on weeds, 2 = reduced weed growth and density, 3 = proper reduction in growth and population, 4 = effective weed destruction, 5 = complete weed eradication. Corn marigold biomass (kg/plot) at crop physiological maturity from the whole plot area was recorded and weed control efficacy was calculated using the following formula (Mahesh, Singh, 2019):

Table 2 - Detail descriptions of experimental treatments

Trade name	Chemical name	Rate	Application time (DAS)	Water rate	Hand weeding	Application time (DAS)
Pallas 45 OD	Pyroxsulam 45 g L^{-1}	0.5 L ha^{-1}	30	200 L ha^{-1}	One time	60
Quelex™ 200 WG	Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1}	50 g ha^{-1}	30	200 L ha^{-1}	One time	60
Derby 175 SC	Flurasulam 75 g L^{-1} + Flumetsulam 100 g L^{-1}	80 ml ha^{-1}	30	200 L ha^{-1}	One time	60
-	-	-	-	-	Two times	30 and 60
-	-	-	-	-	Weed free	As weed emerged
-	-	-	-	-	G. segetum unweeded	Other weeds weeded two times at 30and 60

NB: DAS=Days after seed sowing

$$\text{Weed control efficiency } (WCE) = \left(\frac{WDC - WDT}{WDC}\right) * 100\ldots \text{ (Eqn. 1)}$$

Where, WDC and WDT are weed dry weight (gm^{-2}) in the control and in any specific treatment, respectively.

Wheat plant height was measured from the ground level to the tip of ten randomly selected plants per plot at physiological maturity. Grain yield (kg ha^{-1}) was measured by harvesting the crop from the whole plot area. At physiological maturity, the shoot biomass of 10 plants selected randomly from the destructive rows was weighed after oven drying the harvested produce till a constant weight. Finally, harvest index was calculated from the plants harvested for shoot biomass and grain yield at physiological maturity. It was calculated by dividing grain yield by the total shoot dry biomass yield (Dai et al., 2016).

$$\text{Harvest index (\%)} = \left(\frac{\text{Seed yield}}{\text{Shoot dry biomass}}\right) * 100\ldots \text{ (Eqn. 2)}$$

In West and Southwest Shewa Zones where corn marigold is a major challenge for wheat production, relative yield loss, actual yield loss and potential yield loss of wheat crop were calculated. Wheat average yield loss due to corn marigold data were obtained from West and Southwest Shewa Zones. Yield data on twice hand weeding (farmers' practice), weedy check and weed free were used for the study. Following formulas were used for calculation of yield losses:

Relative crop yield loss due to weed was calculated as follows:

$$\text{Relative yield loss (\%)} = \left(\frac{\text{MY} - \text{YT}}{\text{MY}}\right) * 100\ldots \text{ (Eqn. 3)}$$

Where, MY = the maximum yield obtained in one of the study treatments, YT = yield from particular treatment

$$\textit{Actual yield loss due to Corn marigold} = \left(\frac{CFy - FPy}{CFy}\right) * 100\ldots \text{ (Eqn. 4)}$$

$$\textit{Potential yield loss due to Corn marigold} = \left(\frac{CFy - CCy}{CFy}\right) * 100\ldots \text{ (Eqn. 5)}$$

Where, CFy = crop yield in corn marigold free plots, FPy = crop yield in farmers' practice, and CCy = crop yield in corn marigold un-weeded check plot.

Data on inputs and their costs were collected for each evaluated weed control option, including the costs of procuring herbicides and planting materials, labor expenses for land preparation, tillage and herbicide application, hand weeding, and wheat harvesting. The cost of Pyroxsulam 45 g L^{-1} (2974-birr L^{-1}), Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} (10913-birr kg^{-1}), and Flurasulam 75 g L^{-1} + Flumetsulam 100 g L^{-1} (8400-birr kg^{-1}) were obtained from the prevailing local market (53.37 Ethiopian Birr = $1 United State during study). The shopping unit value of the knapsack sprayer was 1,200 birr as information gathered from Addis Ababa (central market), Ethiopia. Around West and Southwest Shewa zones, the labor cost man^{-1} day^{-1} ranged from 50–150 birr. In addition, data on the market price of wheat per kilogram were collected at each site. The current market price (as of January 2023) was obtained from farmers who sell wheat in local markets and district extension workers to compute benefit cost ratio.

2.4 Data analysis

The collected data were subjected to analysis of variance using SAS computer software version 9.4. Means were separated using LSD procedure at the 95% confidence level.

2.5 Cost-benefit analysis

The cost-benefit analysis for the proposed management practices, which included herbicidal and cultural (manual weeding) strategies, was determined using the (International Maize and Wheat Improvement Center, 1988) method. During the cost-benefit analysis, the total input cost of production, gross revenue, marginal revenue (MR) and benefit-cost ratio (BCR) were all taken into account. The total input cost (additional expenses for weed and trial management) was calculated by adding all costs (variable + fixed input costs) incurred during the study. Tillage and fertilizer costs, as well as planting and harvesting wages, were considered fixed production costs. While the knapsack sprayer, herbicides, and manpower for pesticide spraying and manual weeding were considered variable production costs.

The gross revenue was calculated by multiplying commercialized price and grain yield (Daramola et al., 2019). The MR was computed as subtracting the total variable costs from the gross revenue (Daramola et al., 2019). In addition, the benefit cost ratio was computed as the proportion of MR (numerator) and total variable cost (denominator) (Daramola et al., 2019).

3. Results and Discussion

The analyses of variance showed significant differences among the tested management options on both the weed and crop parameters. Except for crop plant height, which was not significant, all other management options showed significant differences among themselves (Tables 3 and 4). Different corn marigold management options exhibited different responses for different bread wheat parameters such as spike length, number of seeds per spike, thousand seed weight, grain yield, and harvest index.

3.1 Weed dry weight

Significant variation in corn marigold dry weight existed among the management options (Table 3). The application of Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} supplemented with one hand weeding decreased the weed dry weight by about 44-fold, followed by the application of Pyroxsulam 45 g L^{-1} supplemented with one hand weeding, which decreased the weed dry weight by about 35-fold as compared to the weedy check. In the weed-free plots, no weed dry weight was recorded. Farm family labor is insufficient for timely and adequate management of corn marigold in wheat fields, as it needs

Table 3 - Effect weed management practices on corn marigold dry weight and weed control efficiency (WCE) in bread wheat fields at Woliso and Cheliya during 2020 and 2021.

Treatments	Dry weight (kg ha^{-1})	WCE (%)
Pyroxsulam 45g L^{-1} + one hand weeding	275.00^{cd}	97.22^{a}
Halauxifen-methyl 100g kg^{-1} + Florasulam 100g kg^{-1} + one hand weeding	220.83^{d}	97.78^{a}
Flurasulam 75g L^{-1} + Flumetsulam 100g L^{-1} + one hand weeding	1808.33^{b}	81.47^{c}
Two hand weeding	708.33^{cd}	92.87^{b}
Weed free	0.00^{d}	100.00^{a}
Weedy check	9945.83^{a}	0.00^{d}
Mean	2159.72	78.22
LSD (0.05)	447.37	2.82
CV (%)	25.38	4.42

Means followed by the same letter(s) within a column are not significantly different from each other at 5%.

Table 4 - Effect of weed management practices on crop plant height, tiller number, effective tillers per plant, spike length, seeds per spike, biomass yield, grain yield and harvest index at Woliso and Cheliya during 2020 and 2021.

Treatments	PH	TNT	ENT	SL	SPS	BM	GY	HI
Pyroxsulam 45g L^{-1} + one hand weeding	73.33a	4.49ab	4.23ab	6.95b	47.5b	7225.00a-c	3735.95a	52.68a
Halauxifen-methyl 100g kg^{-1} + Florasulam 100g kg^{-1} + one hand weeding	75.88a	4.91a	4.66a	7.25ab	49.69ab	7750.00a	4004.30a	54.50a
Flurasulam 75g L^{-1} + Flumetsulam 100g L^{-1} + one hand weeding	76.33a	2.79b	2.65b	5.88c	43.33c	7254.17ab	2823.78b	39.19b
Two hand weeding	75.25a	1.95c	1.85c	5.99c	40.83d	6770.83bc	2627.35bc	39.09b
Weed free	76.48a	5.35a	5.08a	7.45a	50.75a	7787.50a	4024.28a	53.83a
Weedy check	73.93a	1.25d	1.19d	4.88d	30.83e	6479.17c	2143.07c	35.40b
Mean	75.2	3.40	3.23	6.4	43.82	7211.11	3226.45	45.78
LSD (0.05)	3.31	0.46	0.44	0.44	2.4	772.04	507.24	6.28
CV (%)	5.4	16.50	14.56	8.41	6.71	13.12	19.26	16.8

PH=plant height (cm), TNT=tillers per plant, ENT= effective tillers per plant, SL=spike length (cm), SPS=seeds per spike, BM=biomass yield (kg ha^{-1}), GY=grain yield (kg ha^{-1}), TSW=thousand seed weight (g), HI=harvest index, Means followed by the same letter(s) within a column is not significantly different from each other at 5%.

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removal as it emerges (Nagassa et al., 2022). Hand-weeding wheat fields is time-consuming and usually done late in the season, after the weeds have reduced crop plant growth. It is especially difficult because of the heavy rain during the main cropping season (Nagassa et al., 2022). As a solution a lot of herbicides were registered and affordable and farmers have been practicing the use of herbicides in Ethiopia for the management of weeds in wheat field. However, the use of any single weed management practice alone is ineffective. Therefore, integration of broad leaf killer herbicides and hand weeding is the most economically feasible, and socially acceptable corn marigold weed in wheat fields.

3.2 Weed Control Efficiency

The effects of weed management strategies on weed control efficiency were significantly different (Table 3). Continual removal of corn marigold as it emerged in the field by hand weeding resulted in eradication, whereas effective destruction of the weed is possible by applying Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} supplemented with one hand weeding followed by application of Pyroxsulam 45 g L^{-1} supplemented with one hand weeding. However, frequent hand-weeding of corn marigold in wheat fields is one of the most difficult tasks faced by farmers, especially during the main cropping season. It requires 4 times weed removals per season to make the field weed-free.

3.3 Yield and yield attributes

The effect of weed management practices on number of tillers per plant, number of effective tillers per plant, spike length, number of seeds per spike, biomass yield, grain yield, thousand seed weight, and harvest index were significantly different, whereas no significant differences among all management practices on the crop height were found (Table 4). However, in all wheat crop yield and yield attributes, no significant differences between weed-free, Halauxifen-methyl 100 g kg^{-1} + Florasulam 100g kg^{-1} spray supplemented with one hand weeding, and Pyroxsulam 45 g L^{-1} spray supplemented with one hand weeding were detected (Table 4). The weed-free plots increased the tillering capacity of the crop by about 3.28-fold, followed by Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} spray supplemented with one hand weeding and Pyroxsulam 45 g L^{-1} spray supplemented with one hand weeding, with increased tillering capacities of about 2.93-fold and 2.60-fold, respectively, as compared to the weedy check.

Weed-free plots, Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} spray supplemented with one hand weeding and Pyroxsulam 45 g L^{-1} spray supplemented with one hand weeding increased spike length and number of seeds per spike by 0.53, 0.49, and 0.42-fold and 0.65, 0.61, and 0.54-fold, respectively, when compared to the weedy check plots. Similarly, weed-free by continuous weed removal, Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} spray supplemented with one-hand weeding and Pyroxsulam 45 g L^{-1} spray supplemented with one-hand weeding increased grain yield and harvest index by 0.88, 0.87, 0.74, and 0.52, 0.54, and 0.49-fold, respectively, when compared to weedy check plots.

3.4 Effect of corn marigold weed on yield loss in wheat

When relative yield loss due to corn marigold management practices was compared, the application of Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} at 50 g ha^{-1} with one supplementary hand weeding produced the lowest yield loss (0.5% of the maximum yield), while the highest yield was obtained from the corn marigold free plots. Beside these management options, the lowest yield loss due to corn marigold (7.16% of the maximum yield) was recorded from the application of Pyroxsulam 45 g L^{-1} at 0.50 L ha^{-1} with one additional hand weeding, whereas the highest yield loss (46.75%) was recorded in the weedy check plots (Table 5). Potential and actual wheat yield losses due to corn marigold were calculated and presented in table 6. The potential wheat yield loss due to corn marigold ranged from 40.3–50.3% whereas the actual wheat yield loss due to the weed ranged from 31.7–45.7% based on the weed density per area (Table 6).

3.5 Cost-benefit analysis

For the integrated use of herbicide application and supplementary hand weeding for the corn marigold

Table 5 - Effect of corn marigold on wheat yield under different weed management practices.

Weed management practices	Relative yield loss (%)
Application of Pyroxsulam 45g L^{-1} supplemented with one hand weeding	7.16
Application of Halauxifen-methyl 100g kg^{-1} + Florasulam 100g kg^{-1} supplemented with one hand weeding	0.50
Application of Flurasulam 75g L^{-1} + Flumetsulam 100g L^{-1}supplemented with one hand weeding	29.83
Two hand weeding	34.71
Weed free	0.00
Weedy check	46.75

management, the MR and BCR were computed for treatment combinations. The cost-benefit analysis showed that significant variation in MR and BCR were observed among the evaluated experimental treatments (Table 7). Comparing the management practices, the most prominent MR (96000- and 87680-birr ha^{-1}) and BCR (2.94 and 2.61) were calculated from application of Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} with supplementary one

Table 6 - Potential yield loss and actual yield loss due to corn marigold at West and Southwest Shewa zones in Ethiopia

Zones	Potential yield loss (%)	Actual yield loss (%)
West Shewa	50.29	45.68
Southwest Shewa	43.30	31.66
Mean	46.75	34.71

Table 7 - Economic feasibility analysis for corn marigold management through the integration of herbicide application and hand weeding at the two locations, Western and Southwestern Shewa Zones in Ethiopia, during the 2021 and 2021 cropping season.

	Activity	Price per Ps	Variable costs/ha	Treatments					
				1. Pyroxsulam 45g L^{-1} + hand weeding	2. Halauxifen-methyl 100g kg^{-1} + Florasulam 100g kg^{-1} + hand weeding	Flurasulam 75g L^{-1} + Flumetsulam 100g L^{-1} + hand weeding	4. Two hand weeding	5. Weed free	Weedy check
Input cost	NPS Fertilizer purchase	41	4062	4062	4062	4062	4062	4062	4062
	UREA Fertilizer purchase	40	3632	3632	3632	3632	3632	3632	3632
	Seed purchase	56	8363	8363	8363	8363	8363	8363	8363
	Pyroxsulam 45g L^{-1} purchase	2974	1487	1487					
	Halauxifen-methyl 100g kg^{-1} + Florasulam 100g kg^{-1} purchase	10913	545.65		545.65				
	Flurasulam 75g L^{-1} + Flumetsulam 100g L^{-1}	8400	672			672			
Labor cost of operation	1st oxen plough	400	2000	2000	2000	1600	2000	2000	2000
	2nd oxen plough	400	1600	1600	1600	1600	1600	1600	1600
	3rd oxen plough	400	1600	1600	1600	1600	1600	1600	1600
	4th oxen plough	400	1600	1600	1600	3000	1600	1600	1600
	Planting	250	3000	3000	3000	3000	3000	3000	3000
	Herbicide application	250	500	500	500	500			
	1st Hand weeding	100	2400					2400	
	2nd hand weeding	100	800	800	800	800	800	800	
	3rd hand weeding	100	600					600	
	4th hand weeding	100	600					600	
Harvest cost	Harvesting	250	5000	5000	5000	5000	5000	5000	5000
Total variable cost (TVC)				33644	32703	33829	31657	35257	30857
Revenue	A. wheat price	32000		32000	32000	32000	32000	32000	32000
	B. tons of wheat harvested per Ha			3.74	4.00	2.82	2.63	4.02	2.14
Gross Revenue (GR)				119680	128000	90240	84160	128640	68480
Marginal Revenue (MR) = GR - TVC				**87680**	**96000**	**58240**	**52160**	**96640**	**36480**
Benefit-cost ratio (BCR) = (MR/TVC)				**2.61**	**2.94**	**1.72**	**1.65**	**2.74**	**1.18**

NB: The cost, gross revenue, marginal revenue was in Ethiopian birr. The wheat market price was estimated as of January 2023.

hand weeding and Pyroxsulam 45 g L^{-1} + one hand weeding, respectively. Conversely, the lowest MR (36480- and 52160-birr ha^{-1}) and BCR (1.18 and 1.65) were computed from the weedy check and two hand weeding, respectively.

The MR obtained from the marketing of goods for each integrated management treatment of corn marigold increased by about 34–149% as compared to corn marigold weedy check. In addition, the BCR obtained for each integrated management treatment of the weed increased from 43 to 165% as compared to the weedy check plot (Table 7). Cost-benefit analysis indicated that integration of Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} with once supplementary hand weeding exhibited the top most MR (96000 Birr ha^{-1}) and BCR (2.94), followed by the integration of Pyroxsulam 45 g L^{-1} with once-supplementary hand weeding corresponding to a MR of 87680-birr ha^{-1} and BCR of 2.61. Overall, integrated use of broad leaf killer herbicides with supplementary hand weeding provides a better MR and BCR than single weed management practices (Table 7).

4. Conclusions

Corn marigold is one of the alien weed species that has infested agricultural crops in many parts of Ethiopia since its introduction. It is a problematic weed that is difficult to manage due to its prolific seed production, fast growth and spread, adaptation to a wide range of environmental conditions, and competitiveness with crops. Integrated effects of herbicide application and hand weeding significantly lowered the weed infestation in the study locations. The current study revealed that application of Pyroxsulam 45 g L^{-1} at a rate of 0.50 L ha^{-1} supplemented with one-hand weeding and Halauxifen-methyl 100 g kg^{-1} + Florasulam 100 g kg^{-1} at a rate of 50 g ha^{-1} supplemented with one hand weeding controlled the weed and increased wheat grain yield.

The MR obtained from the marketing of goods for each integrated management treatment of corn marigold increased by about 34–149% as compared to the weedy check. Similarly, BCR from the selling of the grain for each integrated management treatment of the weed increased from 43 to 165%. Inconclusion integrated management of corn marigold by integrating broad spectrum and/or broad-leaf herbicides supplemented with one hand weeding improved wheat production and productivity by controlling the weed. Forthcoming studies should focus on scaling up and popularizing these technologies in corn marigold weed-infested wheat fields in Ethiopia.

Authors' contributions

GB and MD: data collection and curation. ND and NH: data analysis. ND and NH: data interpretation. ND, NH, and SB: funding acquisition and resources. ND, NH, and SB: project administration. ND: supervision. ND: writing the original draft of the manuscript. ND, NH, and SB: writing, review and editing. All authors read and agreed to the published version of the manuscript.

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