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Effectiveness of pre-emergence herbicide imazethapyr and post-emergence herbicide fenoxaprop-p-ethyl on weed management and flower yield in marigold (*Tagetes erecta L.)*

Abdul Rizal AZ[1*], Aida Femnin Kamalia[1] Dyah Arbiwati[2], Siwi Hardiastuti EK[1]

[1]*Department of Agrotechnology, Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia*.
[2]*Department of Soil Science, Faculty of Agriculture, Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia.*

Corresponding author: Abdul Rizal AZ (*Email: abdul.rizal@upnyk.ac.id*)

Abstract

This study aims to determine the optimal dosage of a pre-emergence herbicide containing imazethapyr and a post-emergence herbicide containing fenoxaprop-p-ethyl for effective weed control, as well as to evaluate their impact on the yield and flower quality of marigold plants. This research was conducted in Wukirsari Village, Cangkringan District, Sleman Regency, Yogyakarta, located at coordinates 7°38'01" S – 7°40'20" S and 110°25'58"E – 110°27'54"E. The site is situated at an altitude of approximately 500 meters above sea level. The study was carried out from June to September 2024. The study was conducted using a Randomized Complete Block Design with a single factor consisting of 10 treatment levels. The treatments were as follows: (H1) imazethapyr at 0.15 kilograms a.i/ha, (H2) imazethapyr at 0.20 kilograms a.i/ha, (H3) fenoxaprop-p-ethyl at 0.10 kilograms a.i/ha, (H4) fenoxaprop-p-ethyl at 0.20 kilograms a.i/ha, (H5) imazethapyr 0.15 kilograms a.i/ha + fenoxaprop-p-ethyl 0.10 kilograms a.i/ha, (H6) imazethapyr 0.15 kilograms a.i/ha + fenoxaprop-p-ethyl 0.20 kilograms a.i/ha, (H7) imazethapyr 0.20 kilograms a.i/ha + fenoxaprop-p-ethyl 0.10 kilograms a.i/ha, (H8) imazethapyr 0.20 kilograms a.i/ha + fenoxaprop-p-ethyl 0.20 kilograms a.i/ha, (H9) mechanical weed control, and (H10) untreated (no weed control). The collected data were analyzed using Analysis of Variance at a 5% significance level. The application of Imazethapyr herbicide at a dose of 0.20 kilograms a.i/ha in combination with Fenoxaprop-p-ethyl at doses of 0.10 kilograms a.i/ha and 0.20 kilograms a.i/ha, as well as mechanical weed control, demonstrated the most effective results in suppressing weed growth in marigold cultivation. All three treatments achieved a weed control efficiency of 100%, which is classified as highly effective. These treatments also resulted in the best overall performance of marigold plants. This was reflected in the highest values recorded for flower diameter, flowering time, number of flowers per plant, total flower weight per plant, flower color intensity, and the longest vase life.

Keywords: Fenoxaprop-p-ethyl, Imazethapyr, Marigold (*Tagetes erecta* L.), weed management.

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1. Introduction

Marigold flowers (*Tagetes erecta* L., Family: Asteraceae) are popular ornamental plants known for their striking appearance and diverse applications. Their vibrant and varied colors make them a preferred choice for decorative use in gardens, ornamental pots, and landscape designs. Beyond their aesthetic value, marigolds offer notable benefits in the fields of health and culinary science. These flowers serve as a natural source of lutein and zeaxanthin, carotenoid compounds widely used in the production of dietary supplements, particularly for supporting eye health and preventing age-related macular degeneration (AMD). Marigold petals contain lutein in concentrations ranging from 0.01% to 0.5%, highlighting their potential as a valuable ingredient in eye health supplements [1-4].

Weeds represent a significant constraint in marigold (Tagetes erecta L.) cultivation, as they compete intensely with crop plants for essential resources, including nutrients, water, sunlight, and space. This competition often results in notable reductions in yield, with the severity of the losses being directly influenced by the intensity of weed interference. Weed competition levels are primarily governed by both the density and species composition of the weed flora. During the marigold growing season, the most commonly observed and dominant weed species include *Echinochloa colonum*, *Parthenium hysterophorus*, *Amaranthus viridis*, *Cynodon dactylon*, *Cyperus rotundus*, *Phyllanthus niruri*, *Portulaca quadrifolia*, *Phyllis minima*, *Cenchrus ciliaris*, and *Alternanthera sessilis* [5].

Effective weed management is crucial to enhancing both vegetative growth and flower yield in marigold production. Although mechanical weed control is often considered the most effective method due to its ability to suppress weeds throughout their entire growth stages it also demands substantial labor and incurs high operational costs.

Mazethapyr (5-ethyl-2-[(RS)-4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl]nicotinic acid) is one of the selective herbicides of the imidazolinone group, which can be applied during both the pre-emergence and post-emergence phases. It has been proven effective in controlling broadleaf weeds and *Imperata cylindrica* (cogon grass), particularly in soybean cultivation and other leguminous crops [6].

Imazethapyr acts systemically and selectively, allowing for flexibility in application either before planting or after crop emergence. Its mechanism of action inhibits weed growth for approximately 14 days after treatment by disrupting photosynthesis, antioxidant defense systems, and carbohydrate metabolism, including sugar and starch processes, as demonstrated in *Arabidopsis thaliana* L [7]. Consequently, imazethapyr presents significant potential as a pre-planting herbicide for effective weed control. Imidazolinone will inhibiting the critical enzyme involved in the biosynthesis of branched-chain amino acids in plants known as acetohydroxyacid synthase (AHAS) enzyme, and also known as acetolactate synthase (ALS**)**. By disrupting this enzymatic activity, the herbicide effectively suppresses weed growth [8-10].

Fenoxaprop-p-ethyl belongs to the phenoxy herbicide group. Chemically, it is known as *ethyl (R)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoate* and is classified within the group of 2-(4-aryloxyphenoxy)propionic acid compounds. Fenoxaprop-p-ethyl (FEN) is a selective post-emergence herbicide used to control perennial grass weeds.

The herbicide works by inhibiting the enzyme acetyl-CoA carboxylase (ACCase), which is located in the chloroplasts of grass weeds. This inhibition disrupts the biosynthesis of fatty acids, which are essential for plant growth and development [8].

As a systemic and contact herbicide, fenoxaprop-p-ethyl is applied after the main crop has emerged and is effective against both annual and perennial grass weeds. It is considered cost-effective and easy to apply. It has been proven effective in controlling major weed species such as *Echinochloa crus-galli L.*, *Leptochloa chinensis L.*, and *Digitaria sanguinalis L.* [11].

The combined application of pre-emergence and post-emergence herbicides, which represents an effective strategy for crop management, enhances maintenance efficiency by reducing weed control costs and minimizing adverse environmental impacts. The selection of appropriate herbicide types and dosages plays a crucial role in the success of weed management in marigold cultivation while also helping to maintain both the productivity and quality of the harvested flowers.

This study aims to identify the optimal dosages of pre-emergence herbicide containing imazethapyr and post-emergence herbicide containing fenoxaprop-p-ethyl that are most effective in suppressing weed growth, improving yield, and enhancing the floral quality of marigold plants (Tagetes erecta L.).

2. Research Method

This study was conducted in Wukirsari Village, located in the Cangkringan District, Sleman Regency, Special Region of Yogyakarta, Indonesia. Geographically, the research site lies between the coordinates 07°38'01" S—07°40'20" S and 110°25'58" E—110°27'54" E, at an elevation of approximately 500 meters above sea level. The research was carried out from June to September 2024.

The marigold seeds used in this study were of the Golden Bloom F1 cultivar. The herbicides tested contained the active ingredients imazethapyr and fenoxaprop-p-ethyl. Manure, NPK fertilizer (16:16:16), and NPK grower fertilizer were applied as part of the nutrient management.

This study employed a completely randomized block design (CRBD) with a single treatment factor consisting of ten levels, as follows:
H_1: Imazethapyr 0.15 kg active ingredient (a.i)/ha,
H_2: Imazethapyr 0.20 kg a.i/ha,
H_3: Fenoxaprop-p-ethyl 0.10 kg a.i/ha,
H_4: Fenoxaprop-p-ethyl 0.20 kg a.i/ha,
H_5: Imazethapyr 0.15 kg a.i/ha + Fenoxaprop-p-ethyl 0.10 kg a.i/ha,
H_6: Imazethapyr 0.15 kg a.i/ha + Fenoxaprop-p-ethyl 0.20 kg a.i/ha,
H_7: Imazethapyr 0.20 kg a.i/ha + Fenoxaprop-p-ethyl 0.10 kg a.i/ha,
H_8: Imazethapyr 0.20 kg a.i/ha + Fenoxaprop-p-ethyl 0.20 kg a.i/ha,
H_9: Mechanical weed control at the 2nd and 4th weeks after planting,
$H1_0$: Control (no weed control applied). Each treatment was replicated three times.

The application of Imazethapyr, a pre-emergence herbicide, was conducted one week prior to planting. Meanwhile, fenoxaprop-p-ethyl, a post-emergence herbicide, was applied two weeks after the plants were established. Mechanical weed control was carried out by manually cutting or removing weeds using mechanical tools around the plants during the second and fourth weeks after planting.

Experimental Plot Preparation

Before soil cultivation, a vegetation analysis was conducted to assess the homogeneity of weed vegetation within the research area. Observations were conducted using a sampling quadrat measuring 0.5 m × 0.5 m. The Summed Dominance Ratio (SDR, expressed as a percentage) and the community coefficient were calculated for each weed species identified.

Soil preparation involved loosening the soil manually using a hoe, followed by the incorporation of goat manure at a rate of 15 tons per hectare. The planting distance for marigolds (Tagetes erecta L.) was 50 cm × 40 cm.

Herbicide Application

Herbicides were applied at the respective treatment dosages using an automatic sprayer with a spray volume of 300 liters per hectare. Imazethapyr was applied as a pre-emergence herbicide seven days before transplanting, while fenoxaprop-P-ethyl was applied as a post-emergence herbicide two weeks after transplanting.

Seedling Preparation

Marigold seeds were sown in seedling trays or nursery pots filled with a growing medium of a 1:1:1 mixture of soil, rice husk charcoal, and manure. Seedlings were transplanted into the experimental plots 21 days after sowing (DAS).

Fertilization

Fertilization was done by dissolving NPK 16:16:16 fertilizer in water at a concentration of 2 g/L. The fertilizer was applied thrice at 1, 2, and 3 weeks after transplanting (WAT). During the generative phase, NPK Grower fertilizer (15-09-20 + TE) was applied twice, at 4 and 5 WAT, using the same concentration of 2 g/L.

Harvesting

Harvesting was conducted when the plants reached 45 days after transplanting. The harvest criteria for marigolds were based on full bloom. Flowers were harvested by cutting the bloom along with the central stem section. Harvesting was performed in the morning to maintain flower quality.

2.1. Observation Parameters

1. Weed Vegetation Analysis

Weed vegetation was assessed using the quadrat method with a square quadrat measuring 0.5 m × 0.5 m to determine the *Summed Dominance Ratio* (SDR). The SDR was calculated using the following parameters:

Absolute Density (AD): The total number of individual species' individual weeds within a sample plot.

Relative Density (RD) $= \frac{\text{Absolute density of a species}}{\text{Total absolute density of all species)}} \text{X}100\%$

Absolute Frequency (AF) = $\frac{\text{Number of plots containing the species}}{\text{otal number of sample plots}} \text{X}100\%$

Relative Frequency (RF) = $\frac{\text{Absolute frequency of a species}}{\text{Total absolute frequency of all species}} \text{X}100\%$

Absolute Dominance (ADo) = The dry weight of the individual weed species in the sample plot.

Relative Dominance (RDo) = $\frac{\text{Absolute dominance of a species}}{\text{Total absolute dominance of all species}} \text{X } 100\%$

The Summed Dominance Ratio (SDR) was calculated using the following formula:

SDR= $\frac{\text{RD+RF+RDo}}{3} \text{X } 100\ \%$

2.2. Weed Community Coefficient (C)

The *Weed Community Coefficient* (C) was used to compare the similarity or dissimilarity between two weed communities in different areas, such as among experimental blocks. The coefficient was calculated using the following formula: C= $\frac{2w}{(a+b)}$ x100 %

Where: W = the sum of the lowest SDR values of each weed species found in both communities,

a = total SDR value of all weed species in community A, b = total SDR value of all weed species in community B. The weed communities are considered homogeneous if C is greater than 75%. If C is less than 75%, the communities are considered heterogeneous.

2.3. Weed Control Efficiency (WCE)

Weed control efficiency was determined using the formula proposed by Mani et al. [12] as follows:

WCE(%)= $\frac{(\mathrm{DWC-DWT}}{\mathrm{DWC})}\ X\ 100\ \%$

Where: WCE = Weed Control Efficiency (%), DWC = Dry weight of weeds in the untreated control plot, DWT = Dry weight of weeds in the treated plot

Weed control efficiency was categorized based on the *Standard Efficacy Test for Herbicide Authorization in Hungary* by Dancza et al. [18], as presented below: WCE Range (%) Category 98.1 – 100.0 (Excellent); 95.1 – 98.0 (Very Good); 90.1 – 95.0 (Good); 82.1 – 90.0 7(Acceptable); 70.1 – 82.0 (Questionable); 50.1 – 70.0 (Weak)[30.1 – 50.0 (Very Weak); 0.1 – 30.0 (Ineffectiv)

2.4. Weed Population and Dry Weight per Species

The weed population was assessed by uprooting all weed species within the observation quadrants. The collected weeds were then sorted and classified according to their respective species. The number of individuals per species was counted and recorded as population data. To determine the dry weight per species, the weed samples were oven-dried at 80°C for 48 hours or until a constant weight was achieved.

2.5. Plant Height

Plant height was measured using a measuring tape from the soil surface to the apical growing point. This parameter was used to monitor vertical plant growth throughout the observation period.

2.6. Flower Diameter

The diameter of the flowers was measured at full bloom using a vernier caliper to ensure precise measurements. This parameter served to evaluate the impact of treatments on flower size.

2.7. Flowering Time

Flowering time was determined by the days after transplanting when the first signs of flower development appeared, specifically when at least 50% of the plants had produced fully developed flower buds.

2.8. Number of Flowers per Plant

The number of flowers per plant was recorded by counting the fully bloomed flowers on each sampled plant. Observations were carried out periodically during the flowering phase.

2.9. Flower Weight per Plant

Flower weight per plant was determined by harvesting all fully bloomed flowers from each sampled plant. The harvested flowers were then weighed to determine the total flower biomass per plant, which indicates the plant's reproductive yield.

2.10. Flower Color

Flower color was observed when the flowers had fully bloomed. The observation was conducted six weeks after planting, using the Munsell Plant Tissue Color Charts as a reference tool to compare and identify the flower colors objectively.

2.11. Vase Life

Vase life, measured in days, refers to the duration for which flowers remain fresh after harvest. The assessment was carried out on fully bloomed flowers placed in containers filled with clean water. The number of days the flowers maintained their freshness was recorded from the day of harvest until visible signs of wilting appeared.

3. Results and Discussion

3.1. Weed Vegetation Analysis Prior to Land Preparation

A weed vegetation analysis was conducted prior to land preparation to determine the composition of the weed species and the level of homogeneity across the experimental site. The analysis identified eight weed species, categorized into three major groups: Grasses **(***Digitaria sanguinalis* SDR = 8%, *Cynodon dactylon* SDR = 34%, *Eleusine indica* SDR = 1%). Broadleaf weeds **(***Cyathula prostrata* SDR = 6%, *Solanum chenopodioides* SDR = 1%, *Hippobroma longiflora* SDR = 6%,*Oplimenus hirtellus* SDR = 4%). Sedges (*Cyperus esculentus* SDR = 41%).

Cyperus esculentus was identified as the most dominant species, exhibiting the highest Summed Dominance Ratio (SDR) of 41%.

Furthermore, the calculated weed community coefficients (C) between treatment blocks were all above 75%, specifically: Block I vs. Block II, C = 84.56%; Block I vs. Block III, C = 78.45%; and Block II vs. Block III, C = 82.3%. According to the criteria established by Chaniago et al. [13], a community coefficient (C) value above 75% indicates a high degree of similarity among weed communities. Therefore, it can be concluded that the weed community across the experimental site is relatively homogeneous, making it suitable for conducting herbicide application trials.

3.2. Summed Dominance Ratio at 4 Weeks After Planting (WAP)

The *Summed Dominance Ratio* (SDR), which represents the effect of each treatment on weed composition at 4 weeks after planting (WAP), is presented in Table 1.

Table 1.
Summed Dominance Ratio (SDR) of Weeds at 4 WAP (%).

No.	Species	Treatment									
		H1	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H10**	**H10**
Broadleaf											
1.P. Oleraceae		17	20.2	12.3	25	12.4	16.7	0	0	0	27.5
2.E. Sumatrensis		0	0	7.5	0	9	12.3	0	0	0	10
3. A. Viridis		0	0	0	11.9	14.3	0	0	0	0	14.3
4. C.rutidospermae		13.4	15.4	30.5	26.3	18.6	32.7	0	0	0	10.7
Grasses											
D. bloody		11	0	0	0	3,0	0	0	0	0	7.1
C. Dactylon		18.3	23.4	9.4	10.5	15.7	0	0	0	0	10.2
Sedges		0	0	0	0	0	0	0	0	0	0
C. Esculentus		40.3	41	40.3	26.3	27	48.3	0	0	0	20.2

Description: H1 = Imazethapyr 0.15 kilograms a.i/ha,H2 = Imazethapyr 0.20 kilograms a.i/ha, H3 = Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha, H4 = Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha

H5 = Imazethapyr 0.15 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha,H6 = Imazethapyr 0.15 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha, H7 = Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha, H8 = Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha H9 = Mechanical weed control, H10 = Untreated control (no weed control applied)

Cyperus esculentus was identified as the dominant weed species across all herbicide treatment applications tested (Table 1). It is ranked the sixteenth worst weed globally [14, 15]. As a perennial species, *C. esculentus* exhibits a high degree of adaptability to various soil types and environmental conditions [14, 16] and propagates effectively through the formation of underground tubers [16]. These biological traits contribute to the difficulty of managing this weed.

The application of imazethapyr as a pre-emergence herbicide or fenoxaprop-P-ethyl as a post-emergence herbicide alone was insufficient to suppress C. esculentus effectively. However, combining these herbicides before and after crop emergence produced significantly better control. Treatments involving Imazethapyr at 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl at 0.10 kilograms a.i/ha (H7) and Imazethapyr at 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl at 0.20 kilograms a.i/ha (H8) were effective in controlling *C. esculentus* as well as other weed species. Comparable results were also achieved with mechanical weed control (H9).

Imazethapyr inhibits root and shoot growth in susceptible weed species through protein and DNA synthesis disruption, making it particularly effective against many grass and broadleaf weeds [17].

3.3. Weed Dry Weight and Weed Control Efficiency

Table 2 presents the dry weight of weeds by species and the efficiency of weed control at 4 Weeks After Planting (WAP).

Table 2.
Weed Dry Weight and Weed Control Efficiency at 4 Weeks After Planting (WAP).

Treatment	Dry weight weeds (g)	Weed Control Efficiency (%)
H1: Imazethapyr 0.15 kilograms a.i/ha	17.79 c	21.8
H2: Imazethapyr 0.20 kilograms a.i/ha	16.66 d	27.2
H3: Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha	15.65 c	21.2
H4: Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha	16.01 c	29.62
H5: Imazethapyr 0.15 kilograms a.i/ha+ Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha	13.97 c	36.69
H6: Imazethapyr 0.15 kilograms a.i/ha+ Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha	12.89 b	43.34
H7: Imazethapyr 0.20 kilograms a.i/ha+ Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha	0 d	100
H8: Imazethapyr 0.20 kilograms a.i/ha+ Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha	0 d	100
H9: Mechanical control	0 d	100
H10: Untreated	22.75 a	22.73a

Note: Means followed by the same letter within a column are not significantly different based on the Least Significant Difference (LSD) test at the 5% significance level.

The dry weight data of the weeds presented in Table 2 indicate that the application of Imazethapyr and Fenoxaprop-p-ethyl herbicides and mechanical control significantly reduced weed biomass compared to the untreated control. No weed growth was observed in treatments with Imazethapyr at 0.20 kilograms a.i/ha combined with Fenoxaprop-p-ethyl at either 0.10 kilograms a.i/ha (H7) or 0.20 kilograms a.i/ha (H8). A similar result was observed with mechanical control (H9). The combined application of pre-emergence Imazethapyr and post-emergence Fenoxaprop-p-ethyl, at respective doses of 0.20 kilograms a.i/ha and 0.10–0.20 kilograms a.i/ha, proved to be highly effective in suppressing weed growth in marigold crops from planting through to harvest.

The individual application of pre-emergence Imazethapyr and post-emergence fenoxaprop-p-ethyl herbicides demonstrated less than 30% weed control efficiency. According to the classification criteria established by Dancza et al. [18] and the European Weed Research Council [19], such efficiency is *ineffective*.

The combined treatments of Imazethapyr at 0.15 kilograms a.i/ha + Fenoxaprop-p-ethyl at 0.10 kilograms a.i/ha (H5) and Imazethapyr at 0.15 kilograms a.i/ha + Fenoxaprop-p-ethyl at 0.20 kilograms a.i/ha (H6) resulted in control efficiencies of 30.69% and 43.34%, respectively, which are classified as *very weak*.

In contrast, the combined treatments of Imazethapyr at 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl at 0.10 kilograms a.i/ha (H7) and Imazethapyr at 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl at 0.20 kilograms a.i/ha (H8) achieved 100% weed control efficiency, falling into the *very effective* category, and were statistically comparable to mechanical weed control (H9).

Although the sole application of pre-emergence herbicides was ineffective, it still reduced weed dry weight (Table 1). The weed control efficacy was significantly enhanced when combined with post-emergence herbicide applications.

3.4. Average Flowering Age, Number of Flowers per Plant, Flower Weight, and Flower Diameter

Table 3 presents the average flowering age, number of flowers per plant, weight, and diameter.

Table 3.
Average flowering age, number of flowers per plant, flower weight, and flower diameter.

Treatment	flowering age (day)	Number of Flowers /Plants	Flower weight	Flower diameter (cm)
H1: Imazethapyr 0.15 kilograms a.i/ha	30.67 a 31.00 a 34.00 a 33.33 a	6.67 d	46.78 d 41.00 de 49.67 d 56.55 cd 80.78 bc	6.13 c
H2: Imazethapyr 0.20 kilograms a.i/ha	31.00 a	7.44 c		6.62 ab
H3: Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha		8.44 c	68.67 d	6.66 abc
H4: Fenoxaprop-p-ethyl 0/20 kilograms a.i/ha	30.67 a	7.34 c		6.39 ab
H5: Imazethapyr 0.15 kilograms a.i/ha+		9.21 b	79.56 bc	6.71 ab
Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha	30.0 a			
H6: Imazethapyr 0.15 kilograms a.i/ha+		9.10 b	108.22 b	5.60 bc
Fenoxaprop-p-ethyl 0,20 kilograms a.i/ha	30.00 a			
H7: Imazethapyr 0.20 kilograms a.i/ha+		12.00 a	112.11 a 16.00 e	6.13 bc
Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha	30.3 a 13.00 a			
H8: Imazethapyr 0.20 kilograms a.i/ha+		12.68 a		7.06 a
Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha				
H9: Mechanical control		12.35 a 1.89 d		7.38 a
H10 Control without control				5.07 c

Note: Means followed by the same letter within a column are not significantly different based on the Least Significant Difference (LSD) test at the 5% significance level.

3.5. Flowering Age of Marigold Plants

Table 3 indicates that the earliest flowering age in marigold plants was observed under the control treatment without weed management. The average flowering age of marigolds ranged from 29 to 31 days after planting. However, under the control condition, flowering occurred significantly earlier at 23 days after planting than in other treatments.

This early flowering can be attributed to competition between weeds and marigold plants, which induces stress in the latter. Stressed plants, particularly those experiencing nutrient deficiencies due to weed competition, may enter the reproductive phase earlier as an adaptive strategy. Under such stress conditions, plants prioritize reproductive development over vegetative growth, leading to earlier flowering [20].

3.6. Number of Flowers per Plant

The number of flowers observed in the untreated control group (H10) differed significantly from all other treatments. The highest average number of flowers per plant was recorded in the mechanical weed control treatment (H9), with 12.35 flowers per plant. This result was significantly different from the treatments of Imazethapyr 0.15 kilograms a.i/ha (H1), Imazethapyr 0.20 kilograms a.i/ha (H2), Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha (H3), Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha (H4), as well as combinations of Imazethapyr 0.15 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha (H5), Imazethapyr 0.15 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha (H6), and Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha (H7). However, it did not differ significantly from the combination treatment of Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha (H8).

The number of branches formed influences the number of flowers per plant. The more branches a plant develops, the greater the number of flowers produced, as flowers typically emerge at the tips of the branches. This finding is consistent with the explanation by Nata et al. [21], who noted that flower production is closely related to the number of plant branches.

3.7. Flower Weight per Plant

The individual application of Imazethapyr and Fenoxaprop-p-ethyl herbicides did not show any significant difference between treatments and produced significantly lower flower weights than the sequential combination of both herbicides. The highest flower weight was observed in the mechanical weed control treatment (H9), averaging 112.11 grams per plant. This result was statistically similar to the combination treatments of Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha (H7) and Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha (H8). Mechanical weed control provided a weed-free environment, which promoted optimal plant growth conditions.

The intensity of competition with weeds highly influences the growth performance of marigold plants. A lower level of weed competition ensures greater availability of essential growth factors such as light, water, and nutrients. These favorable conditions enable the plant to allocate more energy toward flower development.

The number and weight of flowers per plant are closely associated with the number of fully developed blooms. The uptake of nutrients, light, and water is critical in driving photosynthesis. The photosynthates are then translocated via the phloem from the leaves to the floral organs, contributing to increased flower diameter and weight [21].

3.8. Flower Diameter

Observations on flower diameter parameters indicated that the largest flower size was recorded under mechanical weed control treatment (H9), with an average diameter of 7.38 cm. This result was statistically similar to the combined herbicide treatments of Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha (H7) and Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha (H8) but significantly different from the other treatments.

Mechanical weed control, implemented through manual weeding, effectively suppresses weed growth. This method damages weeds' vegetative parts and root systems, hindering their development or causing plant death. Moreover, weeding disturbs the germination process of viable weed seeds, effectively reducing their reproduction and spread [22].

Applying pre-emergence herbicides is crucial in controlling weed growth during the early stages of plant development, especially in the vegetative phase. On the other hand, post-emergence herbicides are more effective in managing weeds during the generative growth stage [23].

The increase in flower diameter observed across the various weed control treatments can be attributed to the reduced competition between the crop and weeds. This reduction improves the availability of essential soil nutrients, supporting optimal vegetative growth, which contributes to the development of larger flowers [5].

3.9. Flower Color and Vase Life of Marigold Plants

Table 4 presents the effect of Imazethapyr and Fenoxaprop-p-ethyl herbicide application on the flower color and vase life of marigold plants.

Table 4.
Flower Color and Vase Life of Marigold Plants.

Treatment	Flower color	Vase life	
H1: Imazethapyr 0,15 kilograms a.i/ha	5Y 8/12	Yellow	6.22 bc
H2: Imazethapyr 0,20 kilograms a.i/ha	5Y8/12	Yellow	6.11 c
H3: Fenoxaprop-p-ethyl 0,10 kilograms a.i/ha	7.5YR 7/10	Yellow red	6.55 bc
H4: Fenoxaprop-p-ethyl 0,20 kilograms a.i/ha	7.5YR 7/10	Yellow red	6.66 bc
H5: Imazethapyr 0,15 kilograms a.i/ha + Fenoxaprop-p-ethyl 0,10 kilograms a.i/ha	5Y 8/12	Yellow	6.66 bc
H6: Imazethapyr 0,15 kilograms a.i/ha + Fenoxaprop-p-ethyl 0,20 kilograms a.i/ha	7.5YR 7/10	Yellow red	6.89 ab
H7: Imazethapyr 0,20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0,10 kilograms a.i/ha	7.5YR 7/10	Yellow red	7.11 a
H8: Imazethapyr 0,20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0,20 kilograms a.i/ha	7.5YR 7/10	Yellow red	7.22 a
H9: Mechanical control	7.5YR 7/10	Yellow red	6.00 c
H10: Control without control	5Y 8/12	Yellow	5.11 d

Note: Means followed by the same letter within a column are not significantly different based on the Least Significant Difference (LSD) test at the 5% significance level.

Information on flower color plays a crucial role for agricultural producers. Beyond its aesthetic value, flower color is an important indicator for various purposes, such as monitoring plant health, early detection of diseases, adjusting nutrient requirements, and estimating chlorophyll levels [24, 25].

Table 4 shows that all treatments herbicide applications, mechanical weed control, and untreated control resulted in flowers with a consistent color classification of 7.5YR 7/10. This color is described as yellow-red (a yellowish-red hue).

The color of marigold flowers is primarily determined by two main pigment groups: carotenoids and flavonoids. Carotenoids produce yellow to red tones, while flavonoids contribute to yellow coloration. In addition to pigmentation, genetic factors also influence the carotenoid content in plants. Genetic variability among plants can affect their capacity to synthesize carotenoid pigments [26].

The vase life of cut flowers is a critical factor influencing overall flower quality. A shorter shelf life can complicate transportation, reduce the ornamental value of the flowers, and ultimately lower their marketability [27]. Marigold flowers have a relatively short vase life, typically between 4 and 6 days.

The treatment without weed control (H10) recorded the shortest vase life, with an average duration of 5.11 days, significantly different from all other treatments. In contrast, the most extended vase life was observed in the treatments involving a combination of herbicides: Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.10 kilograms a.i/ha (H7) and Imazethapyr 0.20 kilograms a.i/ha + Fenoxaprop-p-ethyl 0.20 kilograms a.i/ha (H8), with durations of 7.11 and 7.22 days, respectively (Table 4).

The extended vase life observed in these treatments is attributed to reduced competition between weeds and marigold plants. With less competition, the marigold plants could absorb essential nutrients more effectively, promoting healthier and more vigorous growth. This improved physiological condition enhanced flower quality, including a more extended postharvest freshness period.

4. Conclusion

The application of Imazethapyr herbicide at a dose of 0.20 kilograms a.i./ha in combination with Fenoxaprop-p-ethyl at doses of 0.10 kilograms a.i./ha and 0.20 kilograms a.i./ha, as well as mechanical weed control, demonstrated the most effective results in suppressing weed growth in marigold cultivation. All three treatments achieved a weed control efficiency of 100%, which is classified as highly effective.

Furthermore, these treatments also resulted in the best overall performance of marigold plants. This was reflected in the highest values recorded for flower diameter, flowering time, number of flowers per plant, total flower weight per plant, flower color intensity, and the longest vase life.

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