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Triketone Derivates of Hydroxyl Phenyl Pyruvate Dioxygenase (HPPD) as Potential Herbicides against Diverse Weed Flora in Maize: Efficacy, Phyto-toxicity, Soil Residual Toxicity Impact on Succeeding Sunflower

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Field experiments were conducted for two years during 2016-17 to 2017-18 to evaluate the compatibility of tembotrione 420 SC (Laudis) on maize and its residual effect on succeeding crop.
Methodology: Randomized complete block design with three replications were used. TNAU maize hybrid CO6 variety was sown with spacing of 60cm x 30cm. Seven weed control treatments were

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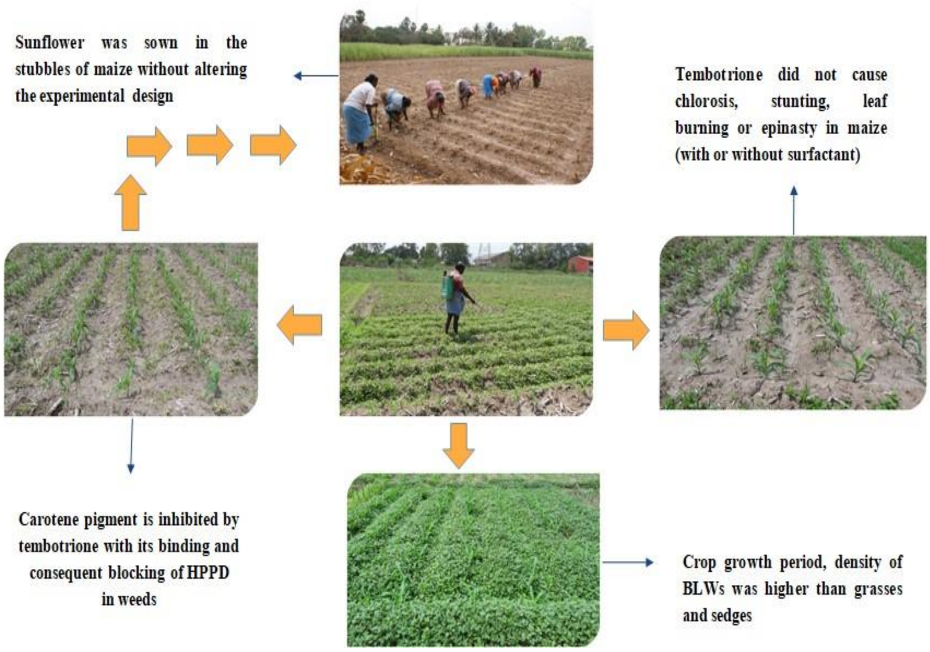
combined with various herbicide dosages followed by tembotrione (420 SC), 2,4-dimethyl amine salt (58% SL), atrazine (50% WP) and surfactant (isoxadifen-ethyl) were sprayed.

Results: POE tembotrione at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine at 500 g a.i.ha^{-1} applied at 2-4 leaf stage provided satisfactory control of all types of weeds (grassy weeds, broad-leaved weeds and sedges) in maize without causing any crop phyto-toxicity on maize, which led to a higher grain yield and improved profitability. It was significantly controlled the dominant grassy and broad-leaved weeds which are *Setaria verticillata* (L.), *Dactyloctenium aegyptium* (L.), *Panicum repens* (L.), *Cyperus rotundus* (L.), *Trianthema portulacastrum* (L.) and *Cleome gynandra* (L.) as compared to the remaining herbicidal treatment. Laudis with different herbicide combinations had no phyto-toxicity on maize and it had no residual toxicity effect in sunflower subsequent crop.

Interpretation: Compatibility of tembotrione (420 SC) at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine (50% WP) at 500 g a.i.ha^{-1} at 20 and 40 DAHS can maintain the total weed density and dry weight at a reasonable level and increase the productivity of *rabi* maize.

Graphical abstract



Keywords: Maize; atrazine; 2; 4-D; HPPD inhibitor; isoxadifen-ethyl; phyto-toxicity; tank mixture.

1. INTRODUCTION

Maize (*Zea mays* L.) is known as the "miracle crop" or "queen of cereals" due to its higher yield potential and tolerance to a variety of environments. The third-most significant food crop in India after rice and wheat, maize holds a proud position as both human food and animal feed. According to the report [1,2]. maize has the ability to increase livelihood security and diversification. Weeds cause yield losses in maize that can range from 27 to 60%, depending on the growth and persistence of the weed population [3-7]. This is because maize has larger row spacing and receives more frequent rains during the *rabi* season. Crucial time for crop weed competition in maize is the first 1 to 8 weeks after seeding. Weeds present during this time impair the efficiency of photosynthesis, dry matter production and the spread to economical viable parts, which in turn reduces the sink capacity of the crop and leads to a lower grain yield. Due to weeds favourable growth conditions, which include frequent rains, broad spacing and initially slow development, *rabi* season, maize is particularly exposed to weed infestations (Das et al*.,* 2012). Regarding the various weed control methods, manual eradication has demonstrated that it is better to all other methods for managing weeds; however, farmers have not embraced the technique due to its time consuming, labour intensity, cost and frequent impracticability during peak seasons [8,2] Herbicides including atrazine, pendimethelin and alachlor were suggested in this case for weed control in maize.

But occasionally, repeated application of a single herbicide (atrazine) can result in the development of herbicide resistance in Tamil Nadu, maize growing region. Therefore, it is essential to examine the efficiency of novel herbicides with a different mechanism of action in maize than atrazine. However, chemical weed management can effectively and affordably suppress weeds throughout this period [9,10]. Furthermore, since most of the maize herbicides used in Tamil Nadu are applied prior to weed emergence, weeds that appear later in the crop's growth cycle are less efficiently controlled. This circumstance called for the start of research projects to assess and choose appropriate PE herbicides. In crops like maize, PE herbicide spraying is a crucial choice because fugitive weeds or weeds later flushes may compete with the crop and provide the weed with weed seed bank [11,12]. Because of its broad control spectrum, exceptional residual activity, high crop tolerance, perceptible speed of efficacy and suitability as a partner for other active ingredients, atrazine has traditionally been used to reduce weed flora [13-15].

Bayer Crop Science introduced tembotrione as a maize herbicide for the first time in 2007 [16,10]. Tembotrione is described as 2-[2-chloro-4-(methylsulfonyl)-3-[(2,2,2 trifloromethoxy) methyl] benzoyl]. A brand-new herbicide for maize named 1,3-cyclohexanedione performs well POST-emergence against a variety of broad-leaved and grassy weeds. It prevents the 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme from converting 4-hydroxyphenylpyruvate to homogentisate, which depletes carotenoids and prevents the development of chloroplasts in developing foliar tissue, giving the plant's appearance a bleached and stunted appearance [17,18]. Light clearly plays a role in the development of HPPD inhibitors herbicidal effect because carotenoids are essential for photosynthesis and photo-protection [19]. Several conferences [20-23], as well as scientific articles from other countries Williams and Pataki, [24] and India [25], discussed the effectiveness of tembotrione as an herbicide. In crops like maize where escaped weeds are a problem, in this situation POE application is a crucial alternative. To maximize weed control efficacy and reduce application costs, it is increasingly common to combine refined pre and post-emergence combinations. In view of their affordability and efficiency in maize, dealing weeds with pre and POE herbicides will be the optimal method for governing the weeds. These tactics are also a crucial tool for avoiding issues with herbicide resistance but they need some background knowledge to help farmers choose the right herbicide and dosage for their particular scenario. With the aforementioned information in mind, it is necessary to find an alternate POE herbicide that may be used in combination to effectively control weeds in *rabi* maize.

2. MATERIALS AND METHODS

2.1 Experimental Site, Design and Initial Soil Properties

A two-year field study was carried out at the Eastern Block (Field No. 74), Tamil Nadu Agricultural University, Coimbatore, India, during the *rabi* seasons of 2016–17 and 2017–18. Three replications of a randomized complete block design were used to arrange the treatments in each year. The experimental farm was located in Western Zone of Tamil Nadu is at 11°29”N latitude and 77°08”E longitude with an altitude of 426.7 m above MSL. The amount of rain that fell at its highest during the cropping season was 76 mm. The soil exhibited a clay loam texture had a pH of 8.52, organic matter of 0.52% and contained low available nitrogen (264 kg ha^{-1}), medium available phosphorus (23.6 kg ha^{-1}) and high accessible potassium (736 kg ha^{-1}).

2.2 Selection of Cultivar, Sowing and Agronomic Practices

Every year, maize (var. TNAU maize hybrid CO6 with a110 days growing season) was used. Recommended fertilizer dose of 150:75:75 kg ha^{-1} was applied for hybrid maize. According to the treatment plan the amount of early POE herbicides was calculated. On 10 to 15 DAS, a new herbicide compound tembotrione 420 SC, was used as a POE (Table 1). The herbicides were applied using a manually operated knapsack sprayer (WFN 40) equipped with a flat fan type nozzle with a 500 litres ha^{-1} spray volume for maize. The treatment plots two border rows on each of their four sides were first harvested and the net plots were collected separately. Each treatments grain weight expressed in kg ha^{-1} was recorded.

2.3 Observation on Weeds

2.3.1 Weed density

In each plot, four randomly selected locations were used to count the weeds using a 0.5 m × 0.5 m quadrant. Weeds that fell within the quadrant's frame were counted and the mean results were represented in number per m^2. At 20 and 40 DAHS, the amount of broad-leaved weeds, grasses and sedges per square metre was counted along with the overall number of weeds.

2.3.2 Weed dry weight

The weeds falling within the quadrant's frame were gathered divided into grasses, sedges and broad-leaved weeds dried in the shade and then dried in a hot-air oven for 72 hours at 80 degrees Celsius. At 20 and 40 DAHS, separate assessments of the dry weight of grasses, sedges and broadleaved weeds were made and quantified in g per m^2.

2.3.3 Weed control efficiency

Weed control efficiency (WCE) was calculated as per the procedure given by Mani et al., [26].

$$\text{WCE \%} = \frac{WD_c - WD_t}{WD_c} \times 100$$

Where,

WCE - weed control efficiency (per cent)

WD_c - weed biomass (g m^{-2}) in control plot

WD_t - weed biomass (g m^{-2}) in treated plot

2.3.4 Weed index

The Gill and Vijaya Kumar (1969) approach was used to obtain the weed index (WI).

$$\text{WI} = \frac{X - Y}{X} \times 100$$

Where, X = yield (kg ha^{-1}) from minimum weed competition plot

Y = yield (kg ha^{-1}) from the treatment plot for which WI is to be worked out.

2.3.5 Grain yield

Each net plot's grain yield was measured in kg ha^{-1} after the grains were cleaned, sun dried, weighed, and rectified to a 14% moisture content.

2.3.6 Phytotoxicity symptoms on crop

The effects of phytotoxicity on the plants were assessed after herbicide treatment. Visual scoring for control of weeds for both the experiments and phyto-toxic symptoms (epinasty / hyponasty / necrosis / wilting / vein clearing) in maize crop were done on 3, 5, 7 and 10 DAHS. The signs of herbicide injury were rated using 0 to 10 scale where 0 = no injury and 10 = complete destruction.

2.3.7 Residual crop cultivation

The next crop of sunflower (TNAU sunflower hybrid CO2) was cultivated in order to evaluate the residual effects of herbicides used on maize without changing the experiment's design. Sunflower was sown in corn stubbles as a follow-up crop after the maize crop was harvested. The percentage of seeds that germinated relative to the total seeds sown was calculated by counting the number of seeds that did so at 10 DAS. Ten harvested plants for each treatment were counted to determine the average quantity of developed seeds per head.

Table 1. Treatments, dosage and formulation of the herbicides

Treatments	g a.i. ha^{-1}	Formulation (g or ml ha^{-1})
T_1 - Tembotrione 420 SC + Surfactant + Atrazine 50% WP	120 + 1000 + 500	286 + 1000 + 1000
T_2 - Tembotrione 420 SC + Surfactant + 2,4-Dimethyl Amine Salt 58% SL	120 + 1000 + 500	286 + 1000 + 860
T_3 - Tembotrione 420 SC + Surfactant	120 + 1000	286 + 1000
T_4 - 2,4-Dimethyl Amine Salt 58% SL	500	860
T_5 - Atrazine 50% WP	500	1000
T_6 - Hand Weeding Twice (20 & 40 DAS)	-	-
T_7 - Unsprayed Control	-	-

DAS - Days After Sowing ; Surfactant - Isoxadifen-ethyl ; Herbicide application - 10 to 15 DAS

2.4 Statistical Analysis

According to the guidelines for randomized block design provided by Gomez and Gomez (2010), the data for rabi maize were statistically analyzed. According to Snedecor and Cochran (1967), the data relevant to weeds and germination was transformed to square root scale and examined. A crucial difference occurred at a 5% probability threshold whenever a significant difference existed. Treatments that had differences that were not statistically significant were designated as NS.

3. RESULTS AND DISCUSSION

3.1 General Weed Flora of the Experimental Field

Among the grasses *Setaria verticillata* (Linn.), *Dactyloctenium aegyptium* (L.) Willd., *Panicum repens* (L.), *Cynodon dactylon* (L.) Pers., and *Chloris barbata* (L.) were the dominant species and the only one sedge weed C*yperus rotundus* (L.). Among the broad leaved weeds *Trianthema portulacastrum* (L.), *Cleome gynandra* (L.), *Amaranthus viridis* (L.), *Commelina benghalensis* (L.), *Boerhaavia diffusa* (L.) *and Pathenium hysterophorus* (L.) were the dominant species. However, a species-wise result was given for the first six weeds only, as they were the predominant weeds in the experimental trial.

3.2 Effect on Weeds

3.2.1 *Setaria verticillata*

Setaria verticillata density in the unsprayed control (22.56 and 28.62 No. m^{-2} in 2017; 18.62 and 23.46 No. m^{-2} in 2018, respectively) recorded higher population of *S. verticillata* at 20 and 40 DAHS (Table 2). During *rabi*, 2017 the lower density of *S. verticillata* was observed by POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (0.86 and 1.02 No.m^{-2}) and this was on par with hand weeding twice on 20 and 40 DAS (1.23 and 4.62 No.m^{-2}). According to Jonathan et al*.,* [27], a tank mix application of the HPPD inhibitor herbicide tembotrione with the atrazine herbicide achieved 95% weed suppression. In this study, POE tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (4.08 and 6.42 No.m^{-2}) was recorded poor control weed of *Setaria verticillata* than that of herbicides alone like atrazine 50% WP at 500 g a.i.ha^{-1} (2.84 and 5.88 No.m^{-2}) and 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (8.68 and 10.22 No.m^{-2}). During *rabi*, 2018, the density of *Setaria verticillata* was significantly influenced by weed control treatments. At 20 and 40 DAHS, POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{1} (0.22 and 1.22 No.m^{-2}) registered lower density of S. *verticillata* and this was followed by hand weeding twice at 20 and 40 DAS (0.42 No./m^2 and 2.16 No.m^{-2}). In the opinion of Joseph et al*.,* [28], tank mixes of tembotrione and atrazine applied post-emergence to maize produced excellent control of grassy weeds.

3.2.1 *Dactyloctenium aegyptium*

Density of *Dactyloctenium aegyptium* in the unsprayed control (6.32 and 9.12 No. m^{-2} in 2017; 5.66 and 8.66 No. m^{-2} in 2018, respectively) registered higher population of *D. aegyptium* at 20 and 40 DAHS (Table 2). During both the years of study, the lower density of *D. aegyptium* was observed in POE application of tembotrione 420 SC at 120 g a.i. ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (0.55 and 0.62 No.m^{-2} in 2017; 0.32 and 0.76 No.m^{-2} in 2018, respectively) and it was similar to the density of hand weeding twice on 20 and 40 DAS (1.06 and 3.06 No.m^{-2} in 2017; 0.16 and 1.98 No.m^{-2} in 2018, respectively). POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (3.14 and 4.02 No.m^{-2} in 2017; 2.65 and 3.18 No.m^{-2} in 2018, respectively) showed effective in reducing its density of *D. aegyptium* as compared to individual application of atrazine 50% WP at 500 g a.i.ha^{-1} (2.08 and 2.96 No.m^{-2} in 2017; 1.80 and 2.76 No.m^{-2} in 2018, respectively) and 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (5.42 and 6.14 No.m^{-2} in 2017; 4.88 and 7.10 No.m^{-2} in 2018, respectively). By inhibiting HPPD, plastoquinone levels are reduced, which leads to a decrease in carotenoids and a lack of chloroplast formation in developing foliar tissue, which causes the tissue to look bleached and stunted [17,12].

3.2.3 *Panicum repens*

The density of *P. repens* in the unsprayed control (5.66 and 6.55 No. m^{-2} in 2017; 3.21 and 6.26 No.m^{-2} in 2018, respectively) registered higher population at 20 and 40 DAHS (Table 2). Weed competition during this crop season decrease the yield up to 40 to 60%, depending on the timing and severity of the weed infestation [29]. POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4- Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (1.72 and 2.96 No.m^{-2} in 2017; 1.56 and 3.46 No.m^{-2} in 2018, respectively) was recorded higher weed density of *P. repens* as compared with tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (0.33 and 0.46 No.m^{-2} in 2017; 0.00 and 0.42 No.m^{-2} in 2018, respectively). Addition of surfactant was also realized essential to achieve satisfactory weed control efficacy of tembotrione against mixed weed flora in maize earlier also given by Singh et al*.,* [25].

3.2.4 *Cyperus rotundus*

During *rabi* 2017, application of POE tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (0.00 and 0.58 No.m^{-2}) proved to be effective in controlling the density of sedge and recorded significantly lower density of *C. rotundus* at 20 and 40 DAHS (Table 3). The findings of Yadav et al*.,* [30], POE tembotrione with surfactant applied early in the growing season, it effectively controlled all types of weeds, including *C. rotundus*, with the highest efficiency at tembotrione 120 g ha^{-1} + surfactant 1000 ml ha^{-1}. However, hand weeding twice on 20 and 40 DAS (0.00 and 0.85 No.m^{-2}) followed by application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (0.68 and 1.26 No.m^{-2}) obtained lesser density of *C. rotundus* at 20 and 40 DAHS. Individual application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml (1.06 and 1.64 No.m^{-2}) and 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (1.32 and 2.20 No.m^{-2}) were ineffective against sedge weed control when compared to herbicide combination. Application of atrazine 50% WP at 500 g a.i.ha^{-1} (0.58 and 1.06 No.m^{-2}) registered lower density of *C. rotundus* when compared to tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml at 20 and 40 DAHS. The lower density of C. *rotundus* was seen during 2018 *rabi* when tembotrione 420 SC was applied at 120 g a.i.ha^{-1} along with surfactant and atrazine 50% WP at 500 g a.i.ha^{-1} (0.36 and 1.02 No.m^{-2}) at all observational stages.

3.2.5 *Trianthema portulocastrum*

Density of *T. portulocastrum* in the unsprayed control plot was 16.88 and 24.56 No. m^{-2} in 2017; 8.56 and 12.66 No.m^{-2} in 2018, respectively (Table 3). Lower density of *T. portulocastrum* was observed in POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (0.56 and 1.86 No.m^{-2} in 2017; 0.23 and 0.86 No.m^{-2} in 2018, respectively). According to Akhtar et al*.,* (2017) tembotrione inhibits the enzyme 4-hydroxy phenyl pyruvate dioxygenase (HPPD), which prevents the production of carotenoids and the depletion of carotenoids, it provides chlorophyll for building blocks of photosynthesis, its defense against light overexposure, leading to chlorophyll oxidation and bleaching of sensitive weeds and plants which eventually turn white. Application of atrazine 50% WP at 500 g a.i.ha^{-1} (2.28 and 6.36 No.m^{-2} in 2017; 1.22 and 2.88 No.m^{-2} in 2018, respectively) was noticed lower density of *T. portulocastrum* and it was closely followed by tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml (3.08 and 9.40 No.m^{-2} in 2017; 2.08 and 4.68 No.m^{-2} in 2018, respectively) during both the years. Application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} was better control of *T. portulocastrum* when herbicide were applied as individual like atrazine, tembotrione, and 2,4-Dimethyl amine salt. This information is very helpful for *rabi* maize farmers in Tamil Nadu to achieve broad spectrum weed control. POE application of tembotrione at 120 g a.i.ha^{-1} (34.4% SC) significantly reduced the density and dry weight of broad leaved weeds over weedy check and it was statistically at par with tembotrione market sample at 120 g a.i.ha^{-1} (34.4% SC), tembotrione at 100, 110 g a.i.ha^{-1} (34.4% SC) and topramezone 33.6 g a.i.ha^{-1}, respectively. These results are in close conformity with those of Lakshmi and Luther [31] reported the superiority of hand weeding over herbicidal treatments.

3.2.6 *Cleome gynandra*

Number of *C. gynandra* in the unsprayed control (6.54 and 8.66 No.m^{-2} in 2017; 2.16 and 3.02 No.m^{-2} in 2018, respectively) recorded higher population of *C. gynandra* at 20 and 40 DAHS (Table 3). POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (2.80 and 4.80 No.m^{-2} in 2017 and 0.68 and 1.76 No.m^{-2} in 2018, respectively) registered higher weed density of *C. gynandra* as compared to

Table 2. Effect of treatments on weed density (No.m^{-2}) at 20 and 40 DAHS in maize

Herbicide treatments	Weed Density (No.m^{-2})											
	2016-17						2017-18					
	Setaria Verticilata		***Dactyloctenium aegyptium***		***Panicum Repens***		***Setaria Verticilata***		***Dactyloctenium aegyptium***		***Panicum repens***	
	20 DAHS	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**
T_1 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml + Atrazine 50% WP at 500 g a.i.ha^{-1}	1.69 (0.86)	1.74 (1.02)	1.60 (0.55)	1.62 (0.62)	1.53 (0.33)	1.57 (0.46)	1.49 (0.22)	1.79 (1.22)	1.52 (0.32)	1.66 (0.76)	1.41 (0.00)	1.56 (0.42)
T_2 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml + 2,4-Dimethyl Amine Salt 58% SL at 500 g a.i.ha^{-1}	2.47 (4.08)	2.90 (6.42)	2.27 (3.14)	2.45 (4.02)	1.93 (1.72)	2.23 (2.96)	2.37 (3.64)	2.81 (5.88)	2.16 (2.65)	2.28 (3.18)	1.89 (1.56)	2.34 (3.46)
T_3 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml	2.75 (5.54)	3.09 (7.56)	2.59 (4.72)	2.75 (5.58)	2.04 (2.18)	2.52 (4.33)	2.68 (5.18)	2.86 (6.20)	2.32 (3.36)	2.68 (5.20)	2.02 (2.08)	2.66 (5.06)
T_4 - 2,4-Dimethyl Amine Salt 58% SL at 500 g a.i.ha^{-1}	3.27 (8.68)	3.50 (10.22)	2.72 (5.42)	2.85 (6.14)	2.24 (3.02)	2.57 (4.62)	3.07 (7.42)	3.38 (9.42)	2.62 (4.88)	3.02 (7.10)	2.18 (2.76)	2.69 (5.24)
T_5 - Atrazine 50% WP at 500 g a.i.ha^{-1}	2.20 (2.84)	2.81 (5.88)	2.02 (2.08)	2.23 (2.96)	1.89 (1.56)	2.16 (2.66)	2.12 (2.51)	2.29 (3.26)	1.95 (1.80)	2.18 (2.76)	1.84 (1.4)	1.94 (1.76)
T_6 - Hand weeding twice on 20 and 40 DAS	1.80 (1.23)	2.57 (4.62)	1.75 (1.06)	2.25 (3.06)	1.78 (1.16)	2.09 (2.36)	1.56 (0.42)	2.04 (2.16)	1.47 (0.16)	1.99 (1.98)	1.41 (0.00)	1.92 (1.70)
T_7 - Unsprayed control	4.96 (22.56)	5.53 (28.62)	2.88 (6.32)	3.33 (9.12)	2.77 (5.66)	2.92 (6.55)	4.54 (18.62)	5.05 (23.46)	2.77 (5.66)	3.26 (8.64)	2.28 (3.21)	2.87 (6.26)
SEd	**0.13**	**0.17**	**0.11**	**0.15**	**0.10**	**0.12**	**0.16**	**0.19**	**0.14**	**0.17**	**0.11**	**0.15**
CD (P=0.05)	**0.24**	**0.33**	**0.22**	**0.31**	**0.20**	**0.24**	**0.32**	**0.38**	**0.28**	**0.34**	**0.20**	**0.32**

Figures in parenthesis are original values; Data subjected to square root transformation; DAHS: Days after herbicide spraying

Table 3. Effect of treatments on weed density (No.m^{-2}) at 20 and 40 DAHS in maize

Herbicide Treatments	Weed Density (No.m^{-2})											
	2016-17						2017-18					
	Cyperus Rotundus		*Trianthema portulocastrum*		*Cleome gynandra*		*Cyperus rotundus*		*Trianthema portulocastrum*		*Cleome gynandra*	
	20 DAHS	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**	**20 DAHS**	**40 DAHS**
T_1 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml + Atrazine 50% WP at 500 g a.i.ha^{-1}	1.41 (0.00)	1.61 (0.58)	1.53 (0.56)	1.96 (1.86)	1.53 (0.33)	1.75 (1.06)	1.54 (0.36)	1.74 (1.02)	1.49 (0.23)	1.69 (0.86)	1.41 (0.00)	1.49 (0.22)
T_2 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml + 2,4-Dimethyl Amine Salt 58% SL at 500 g a.i.ha^{-1}	1.64 (0.68)	1.81 (1.26)	1.75 (2.46)	3.11 (7.68)	2.19 (2.80)	2.61 (4.80)	1.74 (1.04)	2.18 (2.76)	1.79 (1.22)	2.23 (2.96)	1.64 (0.68)	1.94 (1.76)
T_3 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml	1.75 (1.06)	1.91 (1.64)	2.20 (3.08)	3.38 (9.40)	2.20 (2.86)	2.76 (5.64)	1.89 (1.56)	2.50 (4.24)	2.02 (2.08)	2.58 (4.68)	1.79 (1.22)	1.75 (1.08)
T_4 - 2,4-Dimethyl Amine Salt 58% SL at 500 g a.i.ha^{-1}	1.82 (1.32)	2.05 (2.20)	2.35 (4.16)	4.28 (16.36)	2.35 (3.52)	3.52 (10.42)	2.16 (2.68)	2.71 (5.36)	2.36 (3.56)	2.90 (6.40)	1.91 (1.64)	2.15 (2.64)
T_5 - Atrazine 50% WP at 500 g a.i.ha^{-1}	1.61 (0.58)	1.75 (1.06)	1.97 (2.28)	2.89 (6.36)	1.97 (1.88)	2.44 (3.96)	1.71 (0.94)	2.12 (2.48)	1.79 (1.22)	2.21 (2.88)	1.59 (0.54)	1.86 (1.46)
T_6 - Hand weeding twice on 20 and 40 DAS	1.41 (0.00)	1.69 (0.85)	2.19 (0.88)	2.77 (5.68)	1.75 (1.06)	2.14 (2.58)	1.54 (0.36)	1.86 (1.46)	1.60 (0.55)	1.93 (1.72)	1.41 (0.00)	1.63 (0.66)
T_7 - Unsprayed control	2.29 (3.24)	2.41 (3.82)	2.92 (16.88)	5.15 (24.56)	2.92 (6.54)	3.26 (8.66)	2.66 (5.06)	3.10 (7.62)	3.25 (8.56)	3.83 (12.66)	2.04 (2.16)	2.24 (3.02)
SEd	**0.06**	**0.10**	**0.12**	**0.13**	**0.09**	**0.11**	**0.07**	**0.10**	**0.13**	**0.16**	**0.08**	**0.16**
CD (P=0.05)	**0.12**	**0.18**	**0.24**	**0.28**	**0.18**	**0.23**	**0.14**	**0.20**	**0.26**	**0.30**	**0.19**	**0.23**

Figures in parenthesis are original values; Data subjected to square root transformation; DAHS: Days after herbicide spraying

Table 4. Total weed dry weight, weed control efficiency, grain yield and weed index as influenced by different weed management practices in Maize

Herbicide Treatments	Total Weed Dry Weight (g/m^2), WCE (%), Grain Yield (kg/ha) & Weed Index (WI)											
	2016-17						2017-18					
	Total Weed Dry Weight (g/m^2)		WCE (%)		Grain Yield	Weed Index	Total Weed Dry Weight (g/m^2)		WCE (%)		Grain Yield	Weed Index
	20 DAHS	40 DAHS	20 DAHS	40 DAHS			20 DAHS	40 DAHS	20 DAHS	40 DAHS		
T_1 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml + Atrazine 50% WP at 500 g a.i.ha^{-1}	1.98 (1.94)	3.41 (9.66)	92.39	87.48	6880	0.00	1.81 (1.27)	3.48 (10.10)	94.61	86.57	6760	0.00
T_2 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml + 2,4-Dimethyl Amine Salt 58% SL at 500 g a.i.ha^{-1}	2.73 (5.48)	5.15 (24.54)	78.51	68.20	5878	14.56	2.35 (3.50)	4.90 (22.02)	85.16	70.71	5768	14.67
T_3 - Tembotrione 420 SC at 120 g a.i.ha^{-1} + Surfactant at 1000 ml	3.09 (7.52)	5.58 (29.19)	70.51	62.17	5455	20.71	2.97 (6.84)	5.61 (29.47)	70.99	60.80	5220	22.78
T_4 - 2,4-Dimethyl Amine Salt 58% SL at 500 g a.i.ha^{-1}	3.24 (8.50)	5.93 (33.14)	66.67	57.06	5076	26.22	3.23 (8.46)	6.13 (35.52)	64.12	52.75	5016	25.80
T_5 - Atrazine 50% WP at 500 g a.i.ha^{-1}	2.53 (4.38)	4.69 (19.96)	82.82	74.14	6385	7.19	2.41 (3.81)	4.79 (20.94)	83.84	72.15	6180	8.58
T_6 - Hand weeding twice on 20 and 40 DAS	2.25 (3.05)	4.17 (15.41)	88.04	82.64	6560	4.65	2.14 (2.56)	4.25 (16.08)	89.14	78.61	6570	2.81
T_7 - Unsprayed control	5.24 (25.5)	8.90 (77.17)	-	-	3286	52.24	5.06 (23.58)	8.79 (75.18)	-	-	3456	48.88
SEd	**0.12**	**0.25**	**-**	**-**	**243**	**-**	**0.18**	**0.29**	**-**	**-**	**257**	**-**
CD (P=0.05)	**0.26**	**0.45**	**-**	**-**	**488**	**-**	**0.36**	**0.58**	**-**	**-**	**516**	**-**

Figures in parenthesis are original values; Data subjected to square root transformation; DAHS: Days after herbicide sprayi tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (0.33 and 1.06 No.m^{-2} in 2017; 0.00 and 0.22 No.m^{-2} in 2018, respectively). When compared to other herbicidal treatments applied as pre or post-emergence, Singh et al., [25] further confirmed that POE application of tembotrione at 120 g ha^{-1} along with surfactant at 1000 ml ha^{-1} was found to be the most effective to control the grassy as well as non-grassy weeds, with a maximum weed control efficiency of 80-90%. Akhtar et al., (2017) observed that a pigment synthesis inhibitor termed tembotrione, a POE broad-spectrum systemic herbicide of the triketone group, was effective in controlling all categories of weeds infesting maize fields at later stages. Singh et al., [25] and Yadav et al., [32] also reported similar outcomes.

3.3 Total Weed Dry Weight

In Table 4 during both years, lower total weed biomass was observed in POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} (1.94 and 9.66 g m^{-2} in 2017; 1.27 and 10.10 g m^{-2} in 2018, respectively), hand weeding twice on 20 and 40 DAS (3.05 and 15.41 g m^{-2} in 2017; 2.56 and 16.08 g m^{-2} in 2018, respectively) and it was closely followed by application of atrazine 50% WP at 500 g a.i.ha^{-1} (4.38 and 19.96 g m^{-2} in 2017; 3.81 and 20.94 g m^{-2} in 2018, respectively), tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} (5.48 and 24.54 g m^{-2} in 2017; 3.50 and 22.02 g m^{-2} in 2018, respectively). Application of tembotrione at 120 g ha^{-1} + surfactant at 1000 ml ha^{-1} sprayed at the 2-4 leaf stage offered adequate control of all types of weeds in rainy season maize including grassy weeds, broad-leaf weeds and sedges without generating any crop phytotoxicity, which led to a higher grain yield and improved profitability. Yadav et al., [32] concurred that the presence of a surfactant was required in order to successfully use tembotrione against a variety of weed species in maize.

3.4 Weed Control Efficiency

POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} registered higher weed control efficiencies of 92.39 and 87.48% in 2017; 94.61 and 86.57% in 2018, respectively. This was followed by hand weeding twice on 20 and 40 DAS (88.04 and 82.64% in 2017; 89.14 and 78.61% in 2018, respectively) at 20 and 40 DAS (Table 4). According to Triveni et al., [9], manual weeding twice at 20 and 40 DAS was closely followed by WCE with tembotrione 50 g ha^{-1} + atrazine 0.5 kg ha^{-1} as POE and it was considerably greater (93.6 and 96.9%, respectively) than other treatments. Due to increased efficacy across diverse treatments, which may have turned the pendulum in favour of crops rather than weeds, the higher values of WCE can be linked to reduced weed numbers and weed dry weight. Similar findings in maize were also reported by Kolage et al., [33], Singh et al., [25], and Yadav et al., (2012).

3.5 Effect on Crop

3.5.1 Response of grain yield

In 2017 and 2018, the non-treated control plots produced 3286 and 3456 kg ha^{-1} of maize grain respectively, while the yield after all herbicide treatments ranged from 5076 to 6880 kg ha^{-1} and 5016 to 6760 kg ha^{-1} (Table 4). Higher grain yields (6880 kg ha^{-1} in 2017 and 6760 kg ha^{-1} in 2018) were seen in the plots treated with the POE application of the new combination of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1}. Similar findings in maize were also reported by Singh et al., [25] and Santel [34]. The increased number of grains per cob, greater effective plant population and 1000 grain weight in these treatments can be attributable to the better grain production. This enhancement was brought about by better growth characteristics such as increased distribution and total dry matter production. Therefore, lesser crop weed competition resulted in a rise in crop growth and yield components, shifting the balance towards the favour of the crop in terms of nutrient, moisture, light and space utilization [35]. It was comparable to the grain production seen in plots treated with atrazine 50% WP at 500 g a.i.ha^{-1} (6385 kg ha^{-1} in 2017 and 6180 kg ha^{-1} in 2018) and hand weeding twice on 20 and 40 DAS (6560 kg ha^{-1} in 2017 and 6570 kg ha^{-1} in 2018). These results were distinct from those of Swetha [36], who had previously obtained similar results. There have been reports of increased yield attributes following successful weed management with tembotrione and other treatments (Duary et al., [22], Rana et al., [13], Kumar et al., [14,15]. The grain yield in the plots treated with 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} in 2017 and 5016 kg ha^{-1} in 2018 and tembotrione 420 SC at 120 g a.i.ha^{-1} +

surfactant at 1000 ml in both years was similar, but lower than grain yield were recorded. Due to the intense competition that weeds impose and as a result of the poor source and sink development caused by weeds, the lowest grain yield of *rabi* maize was seen in weedy check. The findings of Rout and Satapathy [37], Kolage et al. [33] and Verma et al. [38] were supported by similar results.

3.5.2 Weed index

The best treatment with the highest yield was used as the basis for calculating the weed index, which indicates how much yield was lost owing to weed competition in other treatments. A maximum grain yield was achieved using the herbicide combination of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1}. Hand weeding twice on 20 and 40 DAS during both years resulted in yield reductions of only 4.65% and 2.81% (Table 4). This can be probably ascribed due to improved growth of crops as a consequence of effective control of weeds and reduction in the crop weed competition. This enabled the crop to take up more nutrients attributed to lower weed number and dry weight. The findings of Singh et al*.,* [25] and Yadav et al*.,* [32] are supported by similar findings. The yield reduction was found to be 7.19 and 14.56% in 2017; 8.58 and 14.67% in 2018, respectively, when atrazine 50% WP at 500 g a.i.ha^{-1} and tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + 2,4-Dimethyl amine salt 58% SL at 500 g a.i.ha^{-1} were treated. Therefore, 52.24% in 2017 and 48.88% in 2018 were in unsprayed control plots.

3.6 Phytotoxicity Rating in Maize

Rabi maize was not affected by the application of POE tembotrione 420 SC at 120 g a.i.ha^{-1} with any herbicide combination. The effect of phytotoxicity has been classified as "none". In a field trial conducted in 2017–18 and 2018–19, tembotrione 420 SC at 120 g a.i.ha^{-1} (with or without surfactant) had no phyo-toxicity on maize in terms of chlorosis, stunting, leaf burning or epinasty at 7, 15, 30 and 45 DAHS. According to Rana et al*.,* [39], using tembotrione at a rate of 125–150 g ha^{-1} with (20 DAS) or without (30 DAS) surfactant is an effective substitute for pre followed by post and herbicide mixture applications. Additionally, according to Singh et al*.,* [25], there was no phytotoxicity of tembotrione on maize and the next crop of sunflower in rotation. The findings agree with Hatti et al*.,* [40], According to Kaur et al*.,* [41], the application of tembotrione (100, 110, 120, and 1000 g ha^{-1}) with surfactant at 7, 15, and 30 DAHS had no effect on maize. Hinz et al*.,* [42] observed that maize has a high level of tembotrione tolerance. The results agree with those by Verma et al*.,* [43], according to the findings.

3.7 Soil Residual Toxicity Effect on Succeeding Sunflower

POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} was shown to be considerably superior in registering reduced total weed density in comparison to the other treatments at 40 days after sowing (DAS) during both research years. Germination percentage and number of seeds per head of sunflower showed that the treatments did not significantly differ from one another. Due to varied herbicide combinations of POE application of tembotrione 420 SC at 120 g a.i.ha^{-1} in *rabi* maize throughout both years, the yield of sunflower grown as the next crop exhibited no obvious difference. Yadav et al*.,* [30] observed that there was no residual phytotoxicity on the next wheat following the application of tembotrione at 120 and 240 g ha^{-1} (with surfactant) on maize at 15 and 30 DAHS. When used at the late POE stage in maize, it may have a phytotoxic effect on subsequent mustard or wheat [20,44-46].

4. CONCLUSION

In accordance with the results of the present investigation, POE herbicides such as tembotrione, 2,4-Dimethylamine salt and atrazine showed lesser WCE in the complex weed flora in maize when applied alone. Tembotrione (420 SC) at 120 g a.i. ha^{-1} + surfactant at 1000 ml + atrazine 50% WP at 500 g a.i.ha^{-1} applied at 2-4 leaf stage provided satisfactory control of all types of weeds (grassy weeds, broad-leaved weeds and sedges) in *rabi* maize without causing any crop phyto-toxicity on maize, which led to a higher grain yield and improved profitability. It was determined that adding a surfactant was necessary to ensure that tembotrione was effective against a variety of weed species in maize. Laudis 420 SC (tembotrione 420 SC) with different herbicide combinations had no phytotoxicity on maize and it had no residual toxicity on sunflower subsequent crop either.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Das S, Kumar A, Jat SL, Parihar CM, Singh AK, Chikkappa GK, Jat L. Maize holds potential for diversification and livelihood security. Indian J Agron. 2012; 57:32–37.
2. Alptekin H, Abdullah O, Gurbuz R, Kulak M. Management of weeds in maize by sequential or individual applications of pre and post-emergence herbicides. Agric. 2023;13(2):421. Available:https://doi.org/10.3390/agriculture13020421.
3. Tripathi AK, Tewari AN, Prasad A. Integrated weed management in rainy season maize (*Zea mays* L.) in Central Uttar Pradesh. Indian J. Weed Sci. 2005; 37(3&4):269-270.
4. Sharma CK, Gautam RC. Effect of tillage; Seed rate and weed control methods on weeds and maize (*Zea mays* L.). Indian J. Weed Sci. 2006;38(1&2):58–61.
5. Sunitha N, Reddy MP, Malleswari S. Effect of cultural manipulation and weed management practices on weed dynamics and performance of sweet corn (*Zea mays* L.). Indian J. Weed Sci. 2010;42(3&4): 184–188.
6. Jat RK, Gopar R, Gupta R. Conservation agricultural in maize-wheat cropping systems of eastern India: Weed dynamics and system productivity. In: Extended summaries. International Agronomy Congress, New Delhi, India. 2012;3.
7. Singh AK, Parihar CM, Jat SL, Singh B, Sharma S. Weed management strategies in maize (*Zea mays* L.): Effect on weed dynamics, productivity, and economics of maize wheat (*Triticum aestivum*) cropping system in Indo Gangetic plains. Indian J. Agric. Sci. 2015;85(1):87–92.
8. Dalal LP, Nandkar PB. Effect of biofertilizers and NPK on *Abelmoschus esculentus* (L.) in relation to fruit yield. The Bioscan. 2010;5(2):309–311.
9. Triveni U, Sandhya RY, Patro TSSK, Bharathalakshmi M. Effect of different pre and post-emergence herbicides on weed control, productivity and economics of maize. Indian J. Weed Sci. 2017;49(3): 321–235.
10. Rani N, Duhan A, Tomar D. Ulitimate fate of herbicide tembotrione and its metabolite TCMBA in Soil. 2020;203:111023.
11. Vahedi A, Bakhshi Z, Fakhari R, Vahidipour HR. Evaluation of competitiveness of corn and pigweed in nitrogen levels under pigweed densities by corn yield converse relations. Int. J. Agric Crop Sci. 2013;5: 1442–1444.
12. Khanna N, Bhullar MS, Jaidka M, Kaur T. Maize weed control and yield using different applications of tembotrione. Int. J. Pest Manag; 2022. DOI:https://doi.org/10.1080/09670874.2022.2050833
13. Rana SS, Sharma JJ, Manuja. Evaluation of promising herbicide mixtures for weed control in maize (*Zea mays* L.). New Agriculturist. 1998;9(1&2):1–5.
14. Kumar S, Angiras NN, Rana SS. Integrated weed management in maize. Himachal J Agric Res. 201137(1):1–9.
15. Kumar S, Rana SS, Chander N, Angiras NN. Management of hardy weeds in maize under mid-hill conditions of Himachal Pradesh. Indian J. Weed Sci. 2012;44:11–17.
16. Gatzweiler E, Hansjorg K, Hacker E, Hills K M. Trabold and G. Bonfig-Picard. Weed spectrum and selectivity of tembotrione under varying environmental conditions. 25th German conference on weed biology and weed control, March 13-15, Braunschweig, Germany,. 2012;385–3910
17. Hawkes TR. Hydroxy Phenyl Pyruvate Dioxygenase (HPPD) - The herbicide target. In: Kramer W and Schirmer U (Eds.): Modern Crop Protection Compounds. 2007;1:211–220.
18. Sachan DS, Khan NN, Sachan R, Singh S, Gangwar P, Singh B, Kumar MM. Effect of chemical herbicides on diversified weed flora and weed control efficiency in maize (*Zea mays* L.) International Journal of Plant & Soil Science, 2023;35(17):54-61. Article no.IJPSS.102353 ISSN: 2320-7035 (2023).
19. Heap I. The International Herbicide-Resistant Weed Database; 2022.

Available:http://www.weedscience.org. Accessed: March 11 (2022).
20. Young BG, Zollinger RK, Bernards ML. Variability of tembotrione efficacy as influenced by commercial adjuvant products. Proceedings North Central Weed Science Society. 2007;62:141
21. Lamori DJ, Schwarzlose G, Mahoney M, J. Cantwell, Bloomberg J. Tembotrione mixes with commercial adjuvant packages. Proceedings: North Central Weed Science Society. 2010;65: 124.
22. Duary B, Sharma P, Teja KC. Effect of tank-mix application of tembotrione and atrazine on weed growth and productivity of maize. 25th Asian-Pacific Weed Science Society Conference on Weed science for sustainable agriculture, environment and biodiversity, Hyderabad, India. 2015;98.
23. Kumar J, Kumar A, Sharma V, Bharat R, Singh AP. Bio-efficacy of post emergence tembotrione on weed dynamics and productivity of *kharif* maize in rainfed foothill and mid hill conditions. 25th Asian-Pacific weed science society conference on weed science for sustainable agriculture, environment and biodiversity, Hyderabad, India. 2015;117.
24. Williams MM, Pataky JK. Genetic basis of sensitivity in sweet corn to tembotrione. Weed Sci. 2008;56:364–370.
25. Singh VP, Guru SK, Kumar A, Banga A, Tripathi N. Bioefficacy of tembotrione against mixed weed complex in maize. Indian J. Weed Sci. 2012;44(1):1–5.
26. Mani VS, Mala ML, Gautam KC, Bhagavandas. Weed killing chemicals in potato cultivation. Indian Farming. 1973;23 (1):17–18.
27. Jonathon R, Kohrt, Christy L. Sprague. Weed height and the inclusion of atrazine influence control of multiple resistant Palmer amaranth with HPPD inhibitors. Weed Technol. 2013;43(2).
28. Joseph D, Bollman M, Roger LB, Fritz B. Efficacy and tolerance to HPPD-inhibiting herbicides in sweet corn. Weed Technol. 2008;22:666–674.
29. Dixit A, Raghuvanshi MS, Singh VP, Kumar S. Efficacy of potassium salt of glyphosate on weed control and yield in transgenic corn. Indian J. Agric. Sci. 2016;86(10): 1324–1332
30. Yadav DB, Yadav A, Punia SS, Duhan A. Tembotrione for post-emergence control of complex weed flora in maize. Indian J. Weed Sci. 2018;50(2): 133–136.
31. Lakshmi PV, Luther MM. Studies on influence of herbicides on nutrient uptake and yield in maize. Int. J. Farm Sci., 2017; 7(1):37-39.
32. Yadav DB, Punia SS, Yadav A. Tembotrione: A new post emergence herbicide for complex weed flora in maize. Proceedings of biennial conference of Indian society of weed science, Thrissur (Kerala). 2012;163.
33. Kolage AK, Shinde SH, Bhilare RL. Weed management in *kharif* maize. J. Maharashtra Agric Univ. 2004;29(1):110–111.
34. Santel HJ, Laudis OD- A new herbicide for selective post emergence weed control in corn (*Zea mays* L.). J. Bayer Crop Sci. 2009;11(I):95–108.
35. Akhtar P, Kumar A, Kumar J, Sharma AK, Bharti V. Efficacy of tembotrione on mixed weed flora and yield of spring maize under irrigated sub-tropical shiwalik foothills 25th Asian-Pacific Weed Science Society Conference on Weed science for sustainable agriculture, environment and biodiversity, Hyderabad, India. 2015;266
36. Swetha K. Weed Management with New Generation Herbicides in *kharif* Maize (*Zea mays* L.). M.Sc. thesis, Department of Agronomy, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad; 2015.
37. Rout D, Satapathy MR. Chemical weed control in rainfed maize (*Zea mays* L.). Indian J Agron. 1996;41(1):51–53.
38. Verma SK, Jaysawal PK, Maurya AC, Kumar S, Yadav DK, V. Pratap. Bio-Efficacy of tembotrione (34.4% SC) on diverse weed flora and productivity of *kharif* maize (*Zea mays* L.). Int. J. Agric. Environ. Biotechnol. 2018;743: 771-775.
39. Rana SS, Badiyala D, Sharma NN, Suresh Kumar. Evaluation of tembotrione against weeds in maize (*Zea mays* L.) under mid hill conditions of Himachal Pradesh. Int. J. Innov. Res. Technol. 2018;5(3):220–226 .
40. Hatti V, Sanjay MT, Ramachandra PTV, MKN, Kalyana B, Kumbar MK. Shruthi. Effect of new herbicide molecules on yield, soil microbial biomass and their phytotoxicity on maize (*Zea mays* L.) under irrigated conditions. The Bioscan. 2014;9(3):1127–1130.

41. Kaur T, Bhullar MS, Kaur S.Tembotrione - A post-emergence herbicide for control of diverse weed flora in maize (*Zea mays* L.) in North-West India. Maydica electronic publication. 2018;1-8
42. Hinz J, Wollam J, Allen J. Weed control with AE 0172747 in corn. Proc. North Cent. Weed Sci Soc. 2005;60:90.
43. Verma A, Gangaiah B, Tonapi V. Efficacy of p-hydroxy-phenyl-pyruvate dioxygenase enzyme-inhibitive tembotrione and topramezone herbicides for weed management in rainy season grain sorghum (*Sorghum bicolor*). Indian J. Agron. 2019;6:67–73.
44. Gill GS, Vijaya Kumar K. Weed Index - A new method of reporting weed control trials. Indian J Agron. 2019;14:96–98.
45. Gomez KA, Gomez AA. Statistical procedures for Agricultural Research. Wiley India Pvt. Ltd., New Delhi, India (2010).
46. Snedecor GW, Cochran WG. Statistical methods. Oxford and IBH Publ. Co., New Delhi. 1967; 593(1967).

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