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Metribuzin-based herbicide combination for management of dominant weed flora to enhance wheat productivity and profitability under Indo-Gangetic plains

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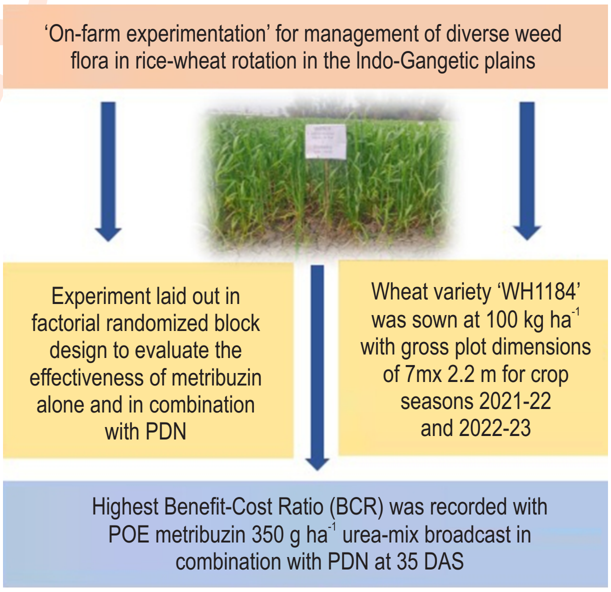
Abstract

Aim: A two-year 'on-farm experimentation' was conducted to estimate the efficacy of metribuzin (MTZ), applied alone and in combination with pinoxaden (PDN), at various application doses and timing for controlling diverse weed flora in rice-wheat cropping system.

Methodology: The experiment was conducted over two consecutive cropping seasons, 2021–22 and 2022–23 at Rice Research Station, CCS Haryana Agricultural University, Kaul (Kaithal), Haryana, India.The experiment with MTZ based herbicide combinations was planned out using factorial randomized block design for management of *Phalaris minor* in wheat under conventional tillage system.

Results: The study results indicated that highest grain yield (6,140 and 5,804 kg ha^{-1} during 2021-22 and 2022-23, respectively.) and Benefit-Cost Ratio (1.96 and 1.83, respectively)was achieved with post-emergence (POE) application of MTZ at 350 g ha^{-1}, mixed with urea and broadcasted at 35 days after sowing (DAS) in conjunction with PDN as spray at 50 g ha^{-1} demonstrating superior weed suppression in wheat crop. PDNat 50 g ha^{-1} exhibited significant control over *Phalaris minor* but demonstrated no effectiveness against broadleaf weeds (BLWs).

Interpretation: POE application of MTZ at 350 g ha^{-1}, broadcasted with urea and PDN at 50 g ha^{-1}, provided highly effective control of *Phalaris minor* and BLWs *viz. Medicago denticulata*, *Melilotus indica* and *Rumex dentatus*. POE application of MTZ at 350 g ha^{-1} and PDN at 50 g ha^{-1} proved to be the most effective and economically viable strategy for weed control in conventional-till wheat.



Key words: Metribuzin, *Phalaris minor*, Pinoxaden, Weed, Wheat

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Introduction

Wheat (*Triticum aestivum* L.), a prominent member of the Poaceae family, is cultivated globally across approximately 220 million hectares, yielding a total production of 771 million tonnes and an average productivity of 3494 kg ha^{-1} (FAOSTAT, 2023). In 2023–2024, the wheat production in India is recorded at 112.92 million tonnes from an area of 31.23 m ha with productivity of 36.15 q ha^{-1} (ICAR-IIWBR, 2024). The North-western Indo-Gangetic Plains (N-W IGPs) of India, encompassing the states of Haryana, Punjab and Uttar Pradesh, constitute a critical wheat-producing region. This region contributes significantly to national production, generating 63.3 million tonnes of wheat from 15.9 million hectares, with an impressive productivity of 3978 kg ha^{-1} (INDIASTAT, 2023). Despite the impressive yields achieved, substantial potential remains to further enhance the productivity by implementing improved agronomic practices, particularly in effective weed management. This is due to the void between the yield potential of promising crop varieties and the actual yields currently obtained by farmers (Evrendilek *et al.,* 2008; Singh *et al.,* 2013). Weeds directly impact wheat productivity by necessitating increased labor for weeding and greater use of herbicides, thereby raising cultivation costs (Puniya *et al.,* 2023; Nath *et al.,* 2024).

Weeds indirectly affect wheat productivity by competing for essential resources, acting as reservoirs for insect pests and pathogens, and interfering with critical agricultural operations such as fertilizer application, irrigation and harvesting. These interactions ultimately lead to reduction in both yield and quality of the wheat crop (Ahlawat *et al.,* 2023a, 2023b; Cudney *et al.,* 2001; Kumar *et al.,* 2013a, 2013b; Soni *et al.,* 2023. Rice-wheat is India's most prominent cropping system. The predominant broadleaf weeds (BLWs) in wheat fields include *Chenopodium album* L., *C. murale* L., *Fumaria parviflora* Lamk., *Convolvulus arvensis* L., *Vicia sativa* L., *Melilotus indicus* L. All., *Anagallis arvensis* L., *Medicago denticulata* L. Syn., *Lathyrus aphaca* L., *Rumex dentatus* L., *Argemone mexicana* L., and *Asphodelus tenuifolius* Cav. In addition, major grassy weeds such as littleseed canary grass (*Phalaris minor* Retz.), foxtail grass (*Polypogon monspeliensis* L. Desf.) and wild oat (*Avena ludoviciana* Durieu) present significant challenges due to their mimicry and competitive abilities, causing serious issues in wheat cultivation (Singh *et al.,* 1995a, 1995b; Dhawan *et al.,* 2009; Punia *et al.,* 2017; Soni *et al.,* 2023).

Phalaris minor has become an increasingly competitive and problematic weed in wheat within the rice-wheat rotation, causing notable reduction in yield (Dhaka *et al.,* 2023; Loura *et al.,* 2023). The cultivation of semi-dwarf, high-yielding wheat varieties require frequent irrigation and higher fertilizer inputs, leading to modifications in the agro-ecological conditions and the creation of a favorable microenvironment for the proliferation and growth of *Phalaris minor*. This weed exhibits strong competitive ability against wheat, as reported by Singh and Malik (1992) and Singh *et al.* (1999, 2021a, 2021b). Furthermore, the rapid development of herbicide resistance in weeds associated with wheat cultivation poses a significant challenge to the sustainability of wheat production systems (Ofosu *et al.,* 2023). Studies indicate the potential for managing herbicide-resistant *Phalaris minor* using dinitroanilines and metribuzin (Yadav *et al.,* 1995; Yaduraju *et al.,* 2000; Chhokar and Sharma, 2008; Dhawan *et al.,* 2012; Yadav *et al.,* 2016). According to Prinsa *et al.* (2018), applying metribuzin @ 210 g ha^{-1} effectively controlled herbicide-resistant populations of *Phalaris minor,* achieving mortality rates ranging from 85 to 100%. However, there are reports on the phyto-toxicity of MTZ on crops (which is variety specific), which restricts its use as an alternate herbicide. The experience at farmers field in Haryana indicates that its application as urea-mix or sand-mix broadcast has lower or no phyto-toxicity, thus, increasing its scope of use for the management of *P. minor* in wheat without any crop phyto-toxicity. In view of the above, this study was conducted identify effective herbicide combinations to manage herbicide-resistant *Phalaris minor,* with the goal of ensuring sustained wheat productivity in northwestern India.

Materials and Methods

Site description: The field experiment was conducted during rabi 2021-22 and 2022-23 within a managed rice-wheat cropping system at Rice Research Station, CCS Haryana Agricultural University, Kaul (Kaithal), India (29° 84´ N latitude and 76° 66´ E longitude, 245 m above mean sea level). The study area experiences a subtropical climate characterized by hot and humid conditions, with an average annual precipitation ranging between 450 to 500 mm. Approximately, 80% of the total rainfall is concentrated during the monsoon season, spanning from July to September. Fig. 1a,b illustrate the agro-meteorological parameters recorded for the study area, providing a comprehensive overview of the climatic conditions relevant to the research. Geographically, experimental field is situated within the Indo-Gangetic plains having clay loam soil with pH of 8.63, indicating a slightly alkaline reaction. The soil organic carbon content in the experimental field was relatively low (0.41%) and available NPK content was 108, 22 and 368 kg ha^{-1}, respectively.

Experimental design and field treatments: The field experiments were set up following a Factorial Randomized Block Design (FRBD) with three replications, comprising sixteen unique treatments. These treatments included the application of MTZ (TATA Metri 70% WP; Tata Rallis, India) alone and in combination with PDN(Axial ® 5.1% EC; Syngenta India Ltd) @ 50 g ha^{-1}. Metribuzin application timings included pre-emergence (PRE), early post-emergence (EPOE) at 21 DAS, and post-emergence (POE) at 35 DAS. The experimental treatments encompassed a spectrum of metribuzin application rates and methodologies, designed to evaluate their effectiveness and optimize application method (spray and urea/sand-mix). PRE spray at 210 and 350 g ha^{-1}, as well as EPOE spray (21 DAS) at 105 g ha^{-1}. Additionally, MTZ was applied @ 210, 280, and 350 g ha^{-1} through broadcast application using a sand and urea mixture and POE (35 DAS) MTZ at 105 g ha^{-1} spray and MTZ at 210, 280 and 350 g ha^{-1} broadcasted with sand and urea-mix. The wheat variety 'WH 1184' was planted on November 7, 2021 and November 21, 2022,

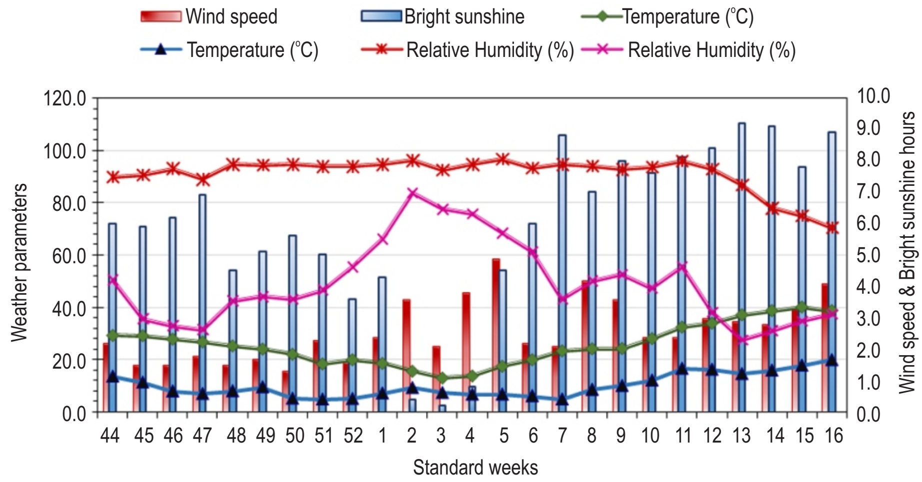

Fig.1a: Mean of weekly meteorological data of RRS, Kaul (Kaithal), Haryana for the crop span (November 2021-April 2022).

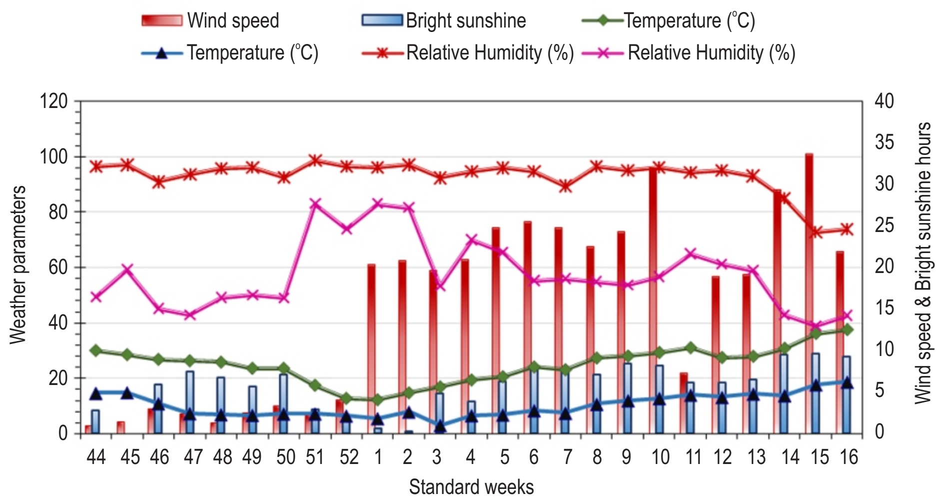

Fig.1b: Mean of weekly meteorological data of RRS, Kaul (Kaithal), Haryana for the crop span (November 2022-April 2023).

maintaining a row spacing of 20 cm. The seeding rate was 100 kg ha^{-1}, and the gross plot dimensions were 7 m × 2.2 m.

Sowing methodology: After ensuring optimal soil moisture in soil at experimental site, a fine seed bed was prepared through a sequence of cultivation practices. Initially, the soil was cultivated twice using a cultivator, followed by the use of a rotavator and seed bed was refined to a suitable tilth by planking with a wooden planker. Wheat was then sown in lines using a tractor-mounted seed cum-fertilizer drill, with ten rows per plot. Crop was supplied with 150 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5 during 2021-22 and 2022-23 cropping seasons. Complete application of phosphorus was administered using diammonium phosphate (DAP), which contains 46% P_2O_5 and 18% N, as a basal fertilizer. At sowing, diammonium phosphate was applied @ 130 kg ha^{-1}, (23 kg of N and 60 kg of P_2O_5 ha^{-1}). Nitrogen was administered in two equal portions: half was applied at sowing, while the remaining half with first irrigation. This was achieved by applying 52 kg of N ha^{-1} as urea broadcasting just prior to wheat sowing (23 kg N ha^{-1} already applied through DAP), followed by an additional application of 75 kg of N h^{-1} as urea broadcast immediately before the first irrigation. No potassium fertilizer was applied, as soil of the experimental site already had sufficient levels of potash (367 kg ha^{-1}). Four irrigation events were conducted to support optimal wheat growth, commencing 22 DAS. Harvesting dates were April 16, 2022 and April 18, 2023 during both seasons, respectively. A knapsack sprayer equipped with flat fan nozzles and with water volume of 500 l ha^{-1} was utilized for herbicide application. Pre-emergence herbicides were applied immediately after sowing, with subsequent applications of EPOE and POE herbicides administered at 21 DAS, prior to irrigation and at 35 DAS, respectively. All the recommended management practices were adhered in accordance with state guidelines, with the exception of the herbicide application for treatment allocation.

Sampling and observations recording: Weed density and biomass were assessed at 90 DAS using a 0.5 m × 0.5 m quadrat by randomly placing at two locations within each plot and data were expressed as number m^2 and dry weight in g m^2, respectively. The crop was harvested manually using sickles and subsequently threshed with a small plot thresher. For dry weight, the collected weed samples were first shade dried and then subjected to further drying in a hot air oven at 65 ± 5°C until a constant weight was achieved and grain yield for each treatment was computed from the net plot area and expressed as q ha^{-1}. The economic analysis was conducted using current market prices for both grain and straw, as well as the cost of cultivation related to each treatment.

Statistical analyses: To assess the variability in key parameters, including weed density, biomass, overall yield and economic performance in wheat, a factorial randomized block design (FRBD) was utilized, and the data were analyzed using Two-way analysis of variance (ANOVA). The data of the experiment was analyzed using 'OPSTAT' (Sheoran *et al.,* 1998). Weed data were evaluated through ANOVA. A post hoc analysis was performed using Fisher's Protected Least Significant Difference (LSD) test to evaluate significant differences among treatment means and identify significant differences, using a significance threshold of p = 0.05. Regression analysis was employed to evaluate the relationship between wheat grain yield (kg ha^{-1}) and weed density (no. m^{-2}) recorded at 90 days after sowing (DAS).

Results and Discussion

Different variables determines how much tillage impact the quantity of the weed seed bank in soil (Mohler, 1993). Infield trial, the predominant grassy weed species identified were *P. minor* Retz. (commonly known as little seed canary grass), which comprised a substantial portion of the grassy weed population. Additionally, *Medicago denticulata* Willd. (bur clover), *Melilotus indica* L. (sweet clover) and *Rumex dentatus* L. (toothed dock) were identified as the major broad-leaved weeds at the site. Herbicides had a significant impact on the density as well as biomass of all weeds especially on grass. During 2021-22 and 2022-23 growing seasons, MTZ applied individually @ 210, 280 and 350 g ha^{-1} was insufficient for satisfactory control of *Phalaris minor.* However, applying PDN @ 50 g ha^{-1} offered effective management of *P. minor.* The efficiency of MTZ for controlling *P. minor* improved notably when combined with PDN. Specifically, POE application of metribuzin at 350 g ha^{-1} mixed with urea, broadcast at 35 DAS, followed by a subsequent POST application of PDN, yielded substantial control over *P. minor* (3.6 and 5.6 plants m^{-2} during 2021-22 and 2022-23, respectively) (Table 1).

The POE application of MTZ at 350 g ha^{-1} via urea-mixed broadcasting, in conjunction with PDN at 50 g ha^{-1}, achieved the maximum control of *P. minor.* This approach resulted in 87.3 and 81.7% higher control during the 2021–22 and 2022–23, respectively, compared to PRE application of MTZ at 210 g ha^{-1} which recorded highest weed density (28.4 and 30.6plants m^{-2} during 2021-22 and 2022-23, respectively). The initial application of metribuzin at PRE rates of 210 and 350 g ha^{-1} demonstrated effective control, but with the advancement of crop stage, the effectiveness of the pre-emergence herbicide decreased due to first irrigation being applied at 22 DAS, which could have led to herbicide leaching and the emergence of subsequent flushes of *P. minor* and other weeds. Abbas *et al.* (2017) recommended the use of herbicide mixtures, such as pinoxaden + metribuzin at 75-100% of recommended doses to manage herbicide resistance population of little seed canary grass in wheat. Similarly, Kaur *et al.* (2016), Rani *et al.* (2018) and Rasool *et al.* (2017) also indicated the influence of herbicide mixtures on major weed flora in wheat crop and concluded that pinoxaden+metribuzin produced higher grain yields in wheat.

Metribuzin, when combined with PDN enhanced broadleaf weed control. Metribuzin applied alone was also effectiveness against these weeds. The maximum reduction in broadleaf weed population was achieved with post-emergence metribuzin at 350 g ha^{-1} mixed with urea, broadcast at 35 DAS in conjunction with pinoxaden (10.1 and 12.3 plants m^{-2} in 2021-22 and 2022-23, respectively) (Table 1). Metribuzin, which has both soil and foliar activity, effectively killed the emerged weeds (first cohort), particularly *P. minor.* The early post-emergence (POE) application of metribuzin before the first irrigation to wheat was also effective, but post-emergence (POE) application was comparatively more effective and both pinoxaden and metribuzin controlled subsequent weed cohorts particularly due to the well-known soil residual activity of metribuzin. However, the efficacy of metribuzin application before the first irrigation was limited as only a few weeds had emerged by that time.

The pre-irrigation application of MTZ effectively controlled the initial cohorts of broadleaf weeds; however, it failed to provide satisfactory control over subsequent flushes of emerging weeds. For broadleaf weeds, the post-emergence application of metribuzin @ 350 g ha^{-1}, when mixed with urea and broadcast at 35 DAS, proved to be effective+ PDN provided satisfactory control during both years. Kumar *et al.* (2013b) also identified metribuzin as the most effective pre-emergence herbicide for wheat crop.

Weed dry biomass accumulation provides a measure of the level of competitive stress imposed by weeds on plants. Effects of different weed management practices on weed dry weight at 90 DAS showed that application of herbicides significantly reduced the biomass of dominant weed flora in field (Fig. 2a,b). In herbicide-treated plots, post-emergence application of MTZ at 350 g ha^{-1}, broadcast as urea mix in combination with PDN as spray, showed high efficacy in

Table 1: Effect of metribuzin (MTZ) and pinoxaden (PDN) on weed density of *P. minor* and broadleaf weeds (No. m^{-2}) in wheat at 90 DAS under conventional tillage

Treatments	*P. minor*						Broadleaf weeds					
	2021-22			2022-23			2021-22			2022-23		
	With PDN	Without PDN	Mean	With PDN	Without PDN	Mean	With PDN	Without PDN	Mean	With PDN	Without PDN	Mean
MTZ-210 spray	3.7 (12.7)	5.4 (28.4)	4.6 (20.6)	4.0 (14.9)	5.6 (30.6)	4.8 (22.8)	6.3 (38.8)	6.2 (37.9)	6.3 (38.4)	6.4 (40.2)	6.4 (39.5)	6.4 (39.9)
MTZ-350 spray	3.7 (12.4)	5.4 (28.0)	4.5 (20.2)	4.0 (14.6)	5.6 (30.1)	4.8 (22.4)	6.3 (38.2)	6.1 (36.1)	6.2 (37.2)	6.4 (40.4)	6.2 (37.5)	6.3 (39.0)
MTZ-105 spray	3.6 (11.8)	5.3 (27.4)	4.5 (19.6)	3.9 (14.0)	5.5 (29.6)	4.7 (21.8)	5.4 (28.3)	5.5 (29.2)	5.5 (28.7)	5.6 (29.9)	5.7 (31.3)	5.6 (30.6)
MTZ-210 sand-mix	3.5 (11.0)	5.2 (26.3)	4.3 (18.7)	3.8 (13.2)	5.4 (28.5)	4.6 (20.9)	5.2 (26.5)	5.3 (27.1)	5.3 (26.8)	5.4 (28.2)	5.5 (29.2)	5.4 (28.7)
MTZ-280 sand-mix	3.4 (10.7)	5.1 (25.5)	4.3 (18.1)	3.7 (12.9)	5.4 (27.8)	4.5 (20.3)	4.8 (22.3)	4.8 (22.1)	4.8 (22.2)	5.0 (24.3)	5.0 (24.1)	5.0 (24.2)
MTZ-350 sand-mix	3.3 (9.9)	5.0 (24.4)	4.2 (17.2)	3.6 (12.0)	5.3 (26.6)	4.4 (19.3)	4.7 (21.1)	4.7 (20.8)	4.7 (20.9)	4.9 (23.0)	4.9 (22.8)	4.9 (22.9)
MTZ-210 urea-mix	3.2 (9.5)	5.0 (24.0)	4.1 (16.8)	3.6 (11.7)	5.2 (26.2)	4.4 (19.0)	4.6 (20.2)	4.5 (19.6)	4.6 (19.9)	4.7 (21.6)	4.8 (22.2)	4.8 (21.9)
MTZ-280 urea-mix	3.2 (9.3)	4.9 (23.3)	4.1 (16.3)	3.5 (11.5)	5.1 (25.4)	4.3 (18.5)	4.4 (18.7)	4.5 (19.0)	4.5 (18.8)	4.6 (20.0)	4.7 (21.1)	4.6 (20.6)
MTZ-350 urea-mix	3.1 (8.6)	4.9 (22.8)	4.0 (15.7)	3.4 (10.8)	5.1 (25.0)	4.3 (17.9)	4.3 (17.8)	4.3 (17.5)	4.3 (17.7)	4.5 (19.4)	4.5 (19.8)	4.5 (19.6)
MTZ-105 spray	2.9 (7.5)	4.8 (22.0)	3.9 (14.8)	3.3 (9.6)	5.0 (24.2)	4.1 (16.9)	4.2 (16.3)	4.3 (17.2)	4.2 (16.7)	4.4 (18.2)	4.5 (19.0)	4.4 (18.6)
MTZ-210 sand-mix	2.8 (7.0)	4.7 (20.7)	3.7 (13.9)	3.2 (9.2)	4.9 (22.9)	4.0 (16.1)	4.2 (16.3)	4.2 (16.6)	4.2 (16.4)	4.3 (17.7)	4.4 (18.4)	4.4 (18.1)
MTZ-280 sand-mix	2.8 (6.7)	4.6 (20.3)	3.7 (13.5)	3.2 (9.1)	4.9 (22.6)	4.0 (15.9)	4.1 (15.7)	4.1 (15.7)	4.1 (15.7)	4.2 (17.1)	4.3 (17.6)	4.3 (17.4)
MTZ-350 sand-mix	2.6 (5.6)	4.4 (18.3)	3.5 (12.0)	2.9 (7.7)	4.6 (20.5)	3.8 (14.1)	3.9 (14.5)	4.0 (15.1)	4.0 (14.8)	4.1 (16.0)	4.2 (16.8)	4.2 (16.4)
MTZ-210 urea-mix	2.4 (4.9)	4.2 (16.9)	3.3 (10.9)	2.9 (7.2)	4.5 (19.0)	3.7 (13.1)	3.9 (13.9)	3.9 (14.5)	3.9 (14.2)	4.1 (15.9)	4.1 (15.5)	4.1 (15.7)
MTZ-280 urea-mix	2.3 (4.5)	3.8 (13.7)	3.1 (9.1)	2.8 (6.8)	4.1 (15.8)	3.4 (11.3)	3.4 (10.9)	3.6 (11.8)	3.5 (11.3)	3.7 (12.8)	3.9 (14.1)	3.8 (13.5)
MTZ-350 urea-mix	3.1 (3.6)	3.7 (13.0)	2.9 (8.3)	2.6 (5.6)	4.0 (15.3)	3.3 (10.5)	3.3 (10.1)	3.5 (11.5)	3.4 (10.8)	3.7 (12.3)	3.8 (13.2)	3.7 (12.8)
Mean	3.0 (8.5)	4.8 (22.2)		3.4 (10.7)	5.0 (24.4)		4.6 (20.6)	4.6 (20.7)		4.8 (22.3)	4.8 (22.6)	
CD (p=0.05)	PDN treatments = 0.03 MTZ treatments = 0.07 PDN × MTZ = 0.10			PDN treatments = 0.04 MTZ treatments = 0.12 PDN × MTZ = 0.13			PDN treatments = NS MTZ treatments = 0.14 PDN × MTZ = NS			PDN treatments = NS MTZ treatments = 0.19 PDN × MTZ = NS		

controlling *P. minor.* This combination reduced the dry weight of *P. minor* when applied as urea-mix than sand-mix at both the stages (21 and 35 DAS) of post-emergence application. In both 2021-22 and 2022-23, among various herbicidal treatments, a notable reduction in broadleaf weed biomass was observed with POE application of MTZ at 350 g ha^{-1}, applied as urea-mix at 35 DAS along with PDN. The superior weed control achieved with herbicide combinations might be due to of extended period of weed control and the broad spectrum of weed species targeted. As demonstrated, season-long and broad-spectrum weed control often require a combination of herbicides. The results are consistent with the findings of Singh *et al.* (2004), Chhokar *et al.* (2006), Kumar *et al.* (2013a) and Kaur *et al.* (2016).

The study demonstrated that weeds present a significant challenge in conventional tillage system for wheat cultivation, leading to substantial yield losses if not effectively managed. The economic yield of wheat is impacted by multiple factors, including weather conditions, weed species and available resources, which influence the biological and morphological development of the

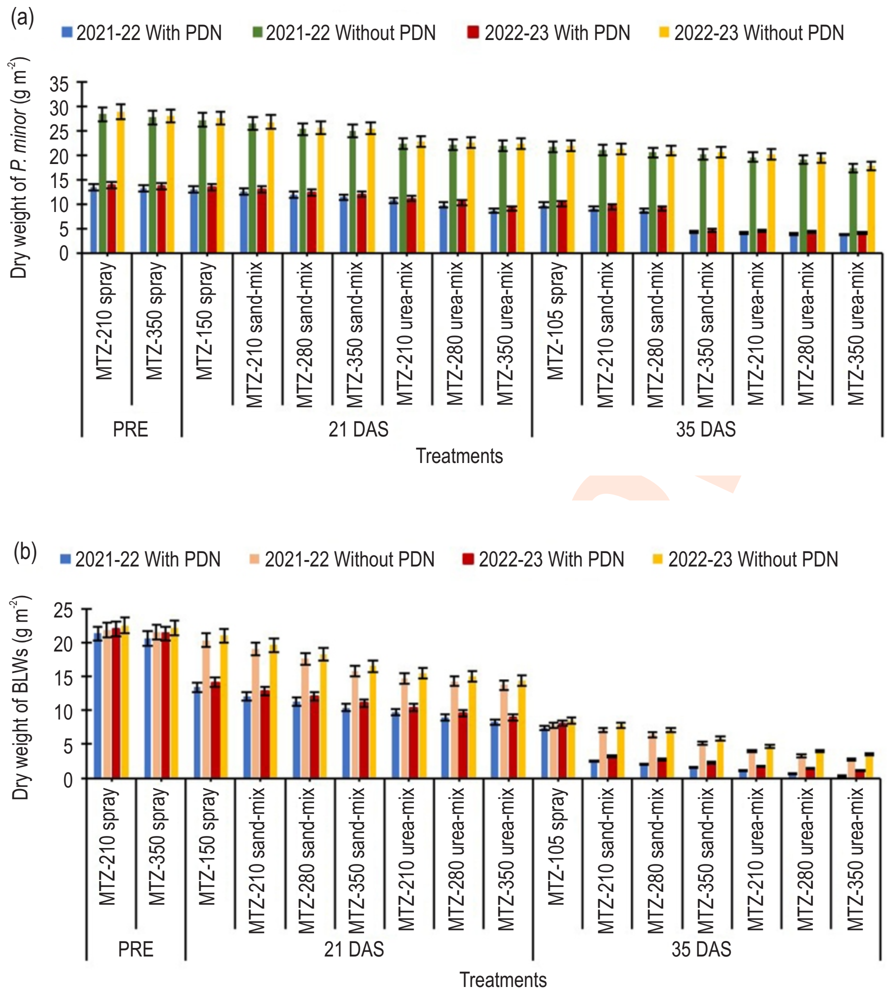

Fig. 2a,b: Effect of metribuzin (MTZ) and pinoxaden (PDN) on dry weight of (a) *P. minor* and (b) BLWs at 90 DAS in conventional tillage condition.

crop. Over a two-year study period, increasing the MTZ application rate from 210 to 350 g ha^{-1} significantly improved the wheat grain yield. The highest yields were achieved with POE application of MTZ at 350 g ha^{-1}, mixed with urea and broadcasted at 35 DAS along with PDN, resulting in 6,140 and 5,804 kg ha^{-1} during 2021-22 and 2022-23 growing seasons, respectively. The application of MTZ at 210 g ha^{-1} as a PRE resulted in the lowest grain yield, exhibiting reduction of 29.0 and 30.6% relative to the POE application of MTZ at 350 g ha^{-1} through urea-mix broadcasting combined with PDN at 50 g ha^{-1} during 2021–22 and 2022–23, respectively. The increased yield observed with this chemical combination, utilizing urea as a carrier instead of sand, can be ascribed to enhanced photosynthetic efficiency of the crop. This improvement likely facilitated superior weed suppression while minimizing phytotoxic effects on the crop. In contrast, the lowest yields were observed with PRE application of MTZ at 210 g ha^{-1} without PDN, producing 4,360 and 4,024 kg ha^{-1} in 2021-22 and 2022-23, respectively (Table 2).

Table 2 presents an economic analysis of various treatment options, evaluating the profitability of agricultural research technologies based on key economic indicators, including net returns and the benefit-cost ratio. The application of herbicide combination, specifically MTZ at 350 g ha^{-1}, broadcasted along with urea and combined with PDN, led to increased net returns and higher benefit-cost ratios (60,476 and 55,864 Rs. ha^{-1} in 2021-22 and 2022-23, respectively). The application of PREMTZ at 210 g ha^{-1}, combined with PDN, resulted in the lowest net returns, amounting to Rs. 25,827 ha^{-1} in 2021-22 and Rs. 19,297 ha^{-1} 2022-23, respectively. Lower grain yield in second year and higher cost of cultivation resulted into reduced net returns during second year in comparison to first year. The benefit-cost ratio is calculated to ascertain the economic viability of herbicidal combinations and highest BCR was recorded under POE MTZ @ 350 g ha^{-1} urea-mix broadcast at 35 DAS in combination with PDN (1.96 and 1.83 in 2021-22 and 2022-23, respectively) closely followed by MTZ 280 g ha^{-1} urea-

Table 2: Effect ofmetribuzin (MTZ) and pinoxaden (PDN) on grain yield, net returns and B-C ratioin wheat at 90 DAS under conventional tillage.

Treatments	Grain yield (kg ha^{-1})						Net returns (Rs. ha^{-1})				B-C ratio			
	2021-22			2022-23			2021-22		2022-23		2021-22		2022-23	
	With PDN	Without PDN	Mean	With PDN	Without PDN	Mean	With PDN	Without PDN	With PDN	Without PDN	With PDN	Without PDN	With PDN	Without PDN
MTZ-210 spray	4,396	4,360	4,378	4,060	4,024	4,042	25,827	27,352	19,297	20,782	1.41	1.45	1.29	1.32
MTZ-350 spray	4,421	4,388	4,405	4,085	4,052	4,069	25,838	27,416	19,335	20,877	1.42	1.46	1.30	1.33
MTZ-105 spray	4,945	4,464	4,705	4,609	4,128	4,369	37,265	29,823	31,338	23,367	1.60	1.50	1.47	1.36
MTZ-210 sand-mix	4,991	4,563	4,777	4,655	4,227	4,441	37,810	31,449	31,934	25,103	1.60	1.52	1.48	1.39
MTZ-280 sand-mix	5,073	4,596	4,835	4,737	4,260	4,499	39,226	31,851	33,440	25,540	1.62	1.52	1.50	1.39
MTZ-350 sand-mix	5,125	4,654	4,890	4,789	4,318	4,554	40,023	32,783	34,295	26,537	1.63	1.54	1.51	1.41
MTZ-210 urea-mix	5,172	4,706	4,939	4,836	4,370	4,603	41,464	34,317	35,787	28,127	1.66	1.57	1.53	1.43
MTZ-280 urea-mix	5,235	4,734	4,985	4,899	4,398	4,649	42,490	34,645	36,883	28,487	1.67	1.57	1.55	1.44
MTZ-350 urea-mix	5,283	4,875	5,079	4,947	4,539	4,743	43,207	37,229	37,653	31,226	1.68	1.61	1.56	1.48
MTZ-105 spray	5,404	5,359	5,382	5,068	5,023	5,046	46,520	47,864	41,099	42,393	1.75	1.80	1.62	1.66
MTZ-210 sand-mix	5,787	5,456	5,622	5,451	5,120	5,286	53,849	49,430	48,849	44,065	1.86	1.82	1.73	1.68
MTZ-280 sand-mix	5,836	5,495	5,666	5,500	5,159	5,330	54,587	49,972	49,640	44,651	1.87	1.82	1.74	1.69
MTZ-350 sand-mix	5,930	5,566	5,748	5,594	5,230	5,412	56,244	51,160	51,402	45,917	1.89	1.84	1.76	1.70
MTZ-210 urea-mix	5,990	5,612	5,801	5,654	5,276	5,465	57,953	52,587	53,177	47,394	1.92	1.87	1.79	1.73
MTZ-280 urea-mix	6,067	5,674	5,871	5,731	5,338	5,535	59,241	53,586	54,549	48,462	1.94	1.88	1.81	1.75
MTZ-350 urea-mix	6,140	5,712	5,926	5,804	5,376	5,590	60,476	54,088	55,864	49,005	1.96	1.89	1.83	1.75
Mean	5,362	5,013		5,026	4,677									
CD (p=0.05)	PDN treatments = 43 MTZ treatments = 121 PDN × MTZ = 171			PDN treatments = 49 MTZ treatments = 138 PDN × MTZ = 195										

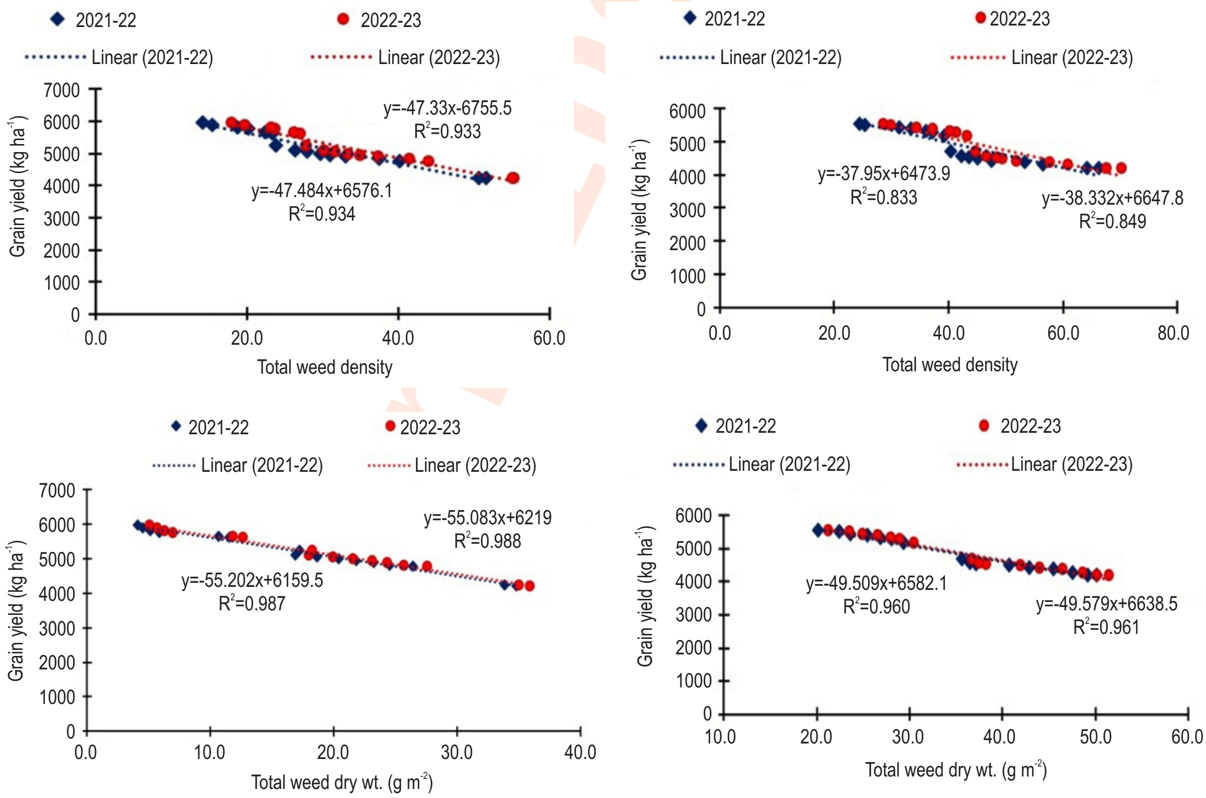

Fig. 3: Relationship between wheat grain yield and total weed density (plants m^{-2}) and dry biomass (g m^{-2}) of dominant weed species analyzed under various treatments of MTZ with PDN (left) and without PDN (right).

mix broadcast at 35 DAS with PDN (1.94 and 1.81 during 2021-22 and 2022-23, respectively). The application of pre-emergence MTZ at 210 g ha^{-1}, in combination with PDN, resulted in the lowest benefit-cost ratio (BCR) among the herbicide treatments, recording values of 1.41 and 1.29 for the years 2021-22 and 2022-23, respectively.

The study demonstrated a pronounced inverse correlation between grain yield and both weed density as well as weed biomass. The consistency of this relationship across varying herbicide dosages was substantiated by the strong goodness-of-fit values demonstrated by the regression model during 2021–22 and 2022–23 growing seasons. Specifically, a linear reduction in wheat grain yield was observed with increasing total weed density at 90 DAS. The higher grain yield was mainly due to the broad-spectrum weed control provided by herbicide combinations, which tilted competition in favor of the crop, leading to higher production of crop. Dominant weeds in total caused 93.4 and 93.3%; 83.3 and 84.9% variation in grain yield of wheat in 2021-22 and 2022–23, with and without PDN, respectively (Fig. 3). During 2021-22 and 2022-23 growing seasons, weed biomass had a substantial impact on wheat grain yield, accounting for 98.8% of yield variance when analyzed with PDN. Additionally, total weed biomass contributed to 96.0 and 96.1% of the variation in grain yield in 2021-22 and 2022-23, respectively, excluding PDN.

Over a two-year study, metribuzin demonstrated high efficacy in managing broadleaf weeds, *viz. Medicago denticulata*, *Rumex dentatus* and *Melilotus indica*. However, its effectiveness was comparatively lower against the main grass weed *Phalaris minor*. Metribuzin 350 g ha^{-1} as urea-mix broadcast at 35 DAS along with post-emergence spray of pinoxaden 50 g ha^{-1} at 35 DAS provided effective control of herbicide resistant population of *Phalaris minor* along with broad leaf weeds in wheat grown under conventional tillage. This could be a viable option for managing troublesome weed in wheat in the North-west Indo-gangetic plains without any phyto-toxicity on the crop. However, before making such recommendations, future studies are advised to be undertaken on its residual carry over in soil, grain as well as straw.

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