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Research Article

ASSESSMENT OF VARIOUS HERBICIDES FOR WEED MANAGEMENT AND THEIR IMPACT ON WHEAT YIELD COMPONENTS IN RICE-WHEAT CROPPING SYSTEM IN PUNJAB, PAKISTAN

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ABSTRACT

Evaluating the efficacy and safety of herbicides is essential for sustainable weed management. This study aims to assess the effectiveness of selected herbicides in controlling weed populations, their impact on wheat growth parameters, and their overall influence on wheat yield components in a rice-wheat cropping system in Punjab, Pakistan. Four herbicides viz. Atlantis Super, Wheat Star, Focal, and Safner were tested alongside an untreated control, using a randomized complete block design across three locations in Punjab. Key parameters evaluated included weed density, biomass, plant height, tillers per plant, 1000-grain weight, and grain yield. Atlantis Super demonstrated the highest weed control efficiency of 79.6%, followed by Wheat Star (76.4%) and Focal (72.7%). These treatments significantly improved crop yield components, with Atlantis Super achieving the highest grain yield of 5.8 t/ha. The study highlights the importance of selecting appropriate herbicides for optimal weed suppression and crop productivity. It also recommends integrated weed management strategies to address herbicide resistance and minimize environmental impacts.

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INTRODUCTION

The rice-wheat cropping system is a vital agricultural practice in South Asia, particularly in Punjab, Pakistan, where it covers approximately 60% of the cultivated area. Weed infestations pose a significant challenge, competing with crops for essential resources such as nutrients, water, and light, leading to substantial yield losses. Therefore, effective weed management practices, including the use of herbicides, are essential for maintaining productivity and sustaining this cropping system (Nawaz et al., 2019; Bhatt et al., 2021).

Weeds are among the most critical factors threatening wheat production, as they compete for fundamental resources such as nutrients, water, light, and space, ultimately reducing crop yield and quality (Flessner et al., 2021). Controlling weeds is crucial for ensuring the sustainability of wheat production. Herbicides have become an integral tool in modern agriculture due to their effectiveness in weed control and their ability to reduce labor costs. Selecting appropriate herbicides and understanding their impact on wheat yield components are essential for optimizing productivity while minimizing environmental impact (Kocira and Staniak, 2021).

Weed infestations in wheat fields cause significant yield losses worldwide. Berhan and Bekele (2021) report that weed interference can reduce wheat yields by 30-60%, depending on weed density, species composition, and the timing of emergence. The critical period for weed competition in wheat typically occurs during the early growth stages, from germination to tillering (Minhas et al., 2023). If weeds are not controlled during this period, yield losses may become irreversible (Storkey et al., 2021).

Safi et al. (2022) reported the impact of herbicides on three wheat varieties. The Crash + U46 treatment outperformed other treatments, enhancing spike density (432.2 spikes/m^2), grains per spike (44.66), and yield (1.8367 t/ha). Among the tested varieties, Samur treated with Crash + U46 recorded the highest yield (1.8933 t/ha) and the most effective weed control (62.26%). These results highlight the efficacy of herbicide mixtures in improving wheat yields.

Herbicides are widely used due to their effectiveness in controlling a broad spectrum of weed species with minimal labor input. They can be categorized based on their mode of action, chemical composition, and timing of application, including pre-emergence and post-emergence herbicides. Pre-emergence herbicides, such as pendimethalin, act on weeds before germination, whereas post-emergence herbicides, such as sulfosulfuron and mesosulfuron-methyl, target actively growing weeds (de Souza Barros et al., 2021).

Similarly, a Hungarian study assessed the effects of intercropping winter wheat and winter pea under different herbicide treatments across two growing seasons. The intercropped plots had fewer weeds than monoculture plots of wheat or pea. Meteorological conditions and weed control practices significantly influenced plant growth and yield. The study highlights the benefits of intercropping and strategic herbicide application for effective weed control and improved crop yields (Kristó et al., 2022).

The integration of herbicides into weed management programs has significantly reduced weed densities and improved wheat yields. Striegel et al. (2021) demonstrated that the application of pre-emergence herbicides reduced weed biomass by 60-80% and increased wheat grain yield by 20-30% compared to untreated controls.

The number of tillers, grain weight, and grain number per spike vary depending on weed competition and herbicide application. Effective weed management minimizes resource competition, thereby improving yield components. Numerous studies have shown that herbicides enhance yield parameters by maintaining a weed-free condition during critical growth stages (Mekonnen, 2022). For instance, Gitsopoulos et al. (2024) reported that the application of post-emergence herbicides significantly improved spike length, grain weight, and overall grain yield in wheat.

However, the indiscriminate use of herbicides can have detrimental effects, including phytotoxicity, soil health degradation, and the development of herbicide-resistant weed species. To mitigate these risks and maximize benefits, selective herbicides should be applied judiciously, with proper dosage optimization and appropriate application timing (Safi and Ramadhan, 2023).

The widespread use of herbicides has sparked concerns regarding their impact on the environment and human health. Residues in soil and water, adverse effects on non-target beneficial organisms, and risks associated with human exposure necessitate careful usage and regulatory oversight (Mohd Ghazi et al., 2023). According to Sookhtanlou and Allahyari (2021), studies recommend adopting eco-friendly herbicides and precision technologies to enhance their targeted application. Assessing various herbicides for weed management in wheat is crucial for improving productivity while ensuring environmental sustainability.

Although herbicides are highly effective, their excessive reliance has led to several environmental and agronomic challenges. Therefore, the development of Integrated Weed Management (IWM) is essential for sustainable weed control, incorporating chemical, cultural, and mechanical methods. Crop rotation and residue management complement herbicide application, reducing dependence on chemicals. Furthermore, using competitive wheat varieties, as suggested by Nurbekov et al. (2024), can further minimize chemical inputs.

Weeds in the rice-wheat cropping system are highly diverse, and although chemical weed control remains popular due to its efficiency and cost-effectiveness, improper herbicide use can result in herbicide resistance, environmental pollution, and biodiversity loss. Thus, evaluating the efficacy and safety of herbicides is critical for sustainable weed management. Therefore, the objective of the present study is to evaluate the efficacy of selected herbicides in controlling weed populations, assess their influence on wheat growth parameters, and determine their overall impact on wheat yield components.

MATERIALS AND METHODS

Study area

The study was conducted at three experimental sites in the Punjab province: Sialkot, Narowal, and Lahore. These locations represent different agro-climatic conditions within the province, with variations in soil types, rainfall patterns, and temperature regimes, which reflect typical conditions for rice-wheat cropping systems.

Experimental design

The experiment was conducted using a randomized complete block design with three replications. Each plot measured 4 m × 4 m, with a 1 m buffer zone between plots to prevent herbicide drift and cross-contamination. Plot preparation followed standard agronomic practices, including plowing, leveling, and fertilizer application.

Treatments

The study evaluated the following herbicides:

1. Focal (Sulfosulfuron 7.5% + Mesosulfuron Methyl 3% + Bio Enhancer)
2. Safner (Clodinafop-Propargyl 15%)
3. Wheat Star (Chlopyralid 30% + Florasulam 30% + Tribenuron Methyl 6%)
4. Atlantis Super (Mesosulfuron-methyl 3% + Iodosulfuron-methyl sodium 0.6% WDG (3.6 WDG))
5. Control (No herbicide application)

Each herbicide was applied at the recommended field rates as specified by the manufacturer.

Herbicide application

A knapsack sprayer was calibrated to deliver a uniform spray volume. Pre-emergence herbicides were applied within 24 h of planting, while post-emergence herbicide sprays were applied 20-25 days after crop emergence when weeds were at the 2-3 leaf stage.

Fertilizer application followed recommended agronomic practices, and irrigation was provided at critical growth stages, including tillering, flowering, and grain filling.

Data collection

Weed density and biomass

Weed density was assessed 30 days after herbicide application to evaluate treatment efficacy. Sampling was conducted using a 0.5 m × 0.5 m quadrat, placed randomly at three locations within each plot to account for spatial variability. The total number of weeds within each quadrat was recorded, and the mean weed density per unit area was calculated.

To assess weed biomass, all weeds within the quadrat were uprooted to include both above-ground and below-ground components. The samples were air-dried to remove surface moisture, then oven-dried at a constant temperature of 70°C until fully dried. The final dry weight was recorded.

Crop yield components

The yield components were measured to assess the effects of treatments on crop performance.

Plant height

Plant height was measured from the base of the plant at the soil surface to the tip of the tallest leaf or panicle using a measuring scale. Measurements were taken from 10 randomly selected plants in each plot to account for intra-plot variability, and the average plant height for each treatment was calculated.

Number of tillers per plant

The number of tillers per plant was recorded from the same 10 randomly selected plants in each plot. Tillers were counted manually, and the average number of tillers per plant was calculated for each treatment.

1000-grain weight

To determine the 1000-grain weight, a random sample of grains was collected from the harvested yield of each plot. Impurities were removed, and the grains were dried to a moisture content of 12-14%. An analytical balance was used to weigh 1000 grains for each treatment.

Grain yield (t/ha)

Grain yield was determined by harvesting the entire plot at physiological maturity. The harvested material was hand-threshed, cleaned, and separated from chaff and other debris. Grain weight was recorded using a digital scale and adjusted to standard moisture content for yield calculation. The yield per plot was then extrapolated to a per-hectare basis (t/ha) using the following formula:

$$\text{Grain yield (t/ha)} = \frac{\text{Grain weight (kg/plot)} \times 10{,}000}{\text{Plot area (m2)}}$$

Weed control efficiency (WCE)

Weed Control Efficiency (WCE) was calculated to assess the effectiveness of herbicide treatments in reducing weed density compared to untreated plots. The WCE formula is:

$$\text{WCE (\%)} = \frac{\text{WDc} - \text{WDt}}{\text{WDc}} \times 100$$

Where:

WDc = Weed density in the untreated control plot

WDt = Weed density in the treated plot

Statistical analysis

Data were analyzed using ANOVA in SPSS software, and treatment means were compared using Fisher's Least Significant Difference (LSD) test at a 5% probability level. Correlation analysis was also performed to examine the relationship between weed density, biomass, and crop yield.

RESULTS AND DISCUSSION

Weed density and biomass

The application of herbicide treatments significantly reduced weed density and biomass compared to the untreated control. As shown in Figure 1, Atlantis Super was the most effective, resulting in the lowest weed density (9.3 plants/m^2) and biomass (100 g/m^2). Wheat Star and Focal also demonstrated high efficacy, with weed densities of 10.8 and 12.5 plants/m^2, respectively. Safner was less effective, with a weed density of 15.2 plants/m^2.

In contrast, the untreated control had the highest weed density (45.7 plants/m^2) and biomass (520 g/m^2), highlighting the critical role of herbicide application in effective weed management.

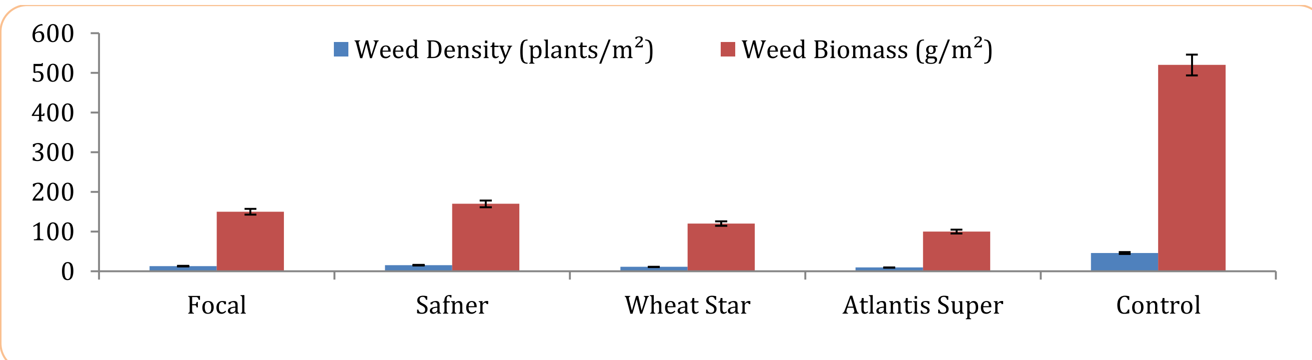

Figure 1: Weed density and biomass across treatments.

Crop yield components

The herbicide treatments had a positive impact on crop yield components, improving plant growth and productivity, as shown in Figures 2 and 3. Atlantis Super resulted in the tallest plants (96.7 cm) and the highest number of tillers per plant (7.8), closely followed by Wheat Star (96.3 cm, 7.5 tillers) and Focal (96.1 cm, 7.2 tillers). In contrast, the untreated control produced the shortest plants (85.2 cm) and the fewest tillers per plant (5.6), highlighting the negative impact of high weed competition on crop development.

Regarding yield performance, Atlantis Super recorded the highest grain yield (5.8 t/ha) and 1,000-grain weight (42.1 g), followed by Wheat Star (5.6 t/ha, 41.8 g) and Focal (5.6 t/ha, 40.9 g). The untreated control had the lowest grain yield (4.3 t/ha) and 1,000-grain weight (35.3 g), further emphasizing the detrimental effects of weed interference on crop productivity.

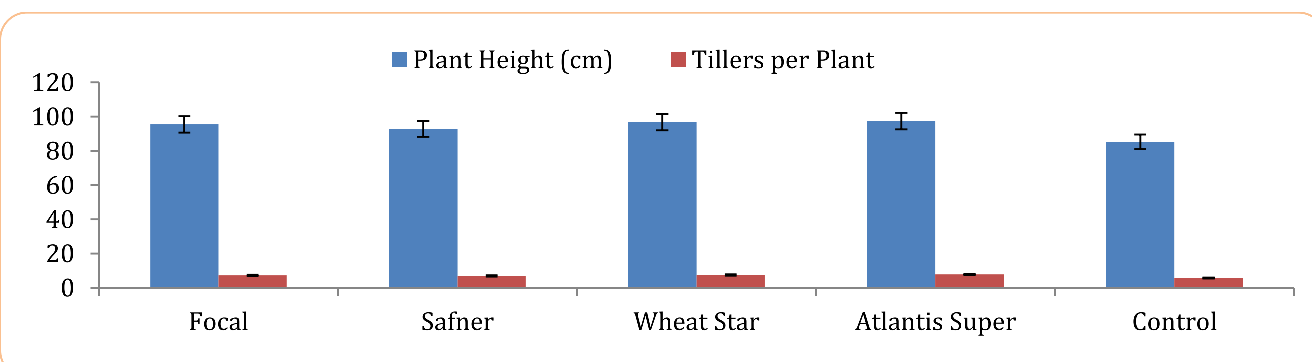

Figure 2: Effect of treatments on plant height and tillers per plant.

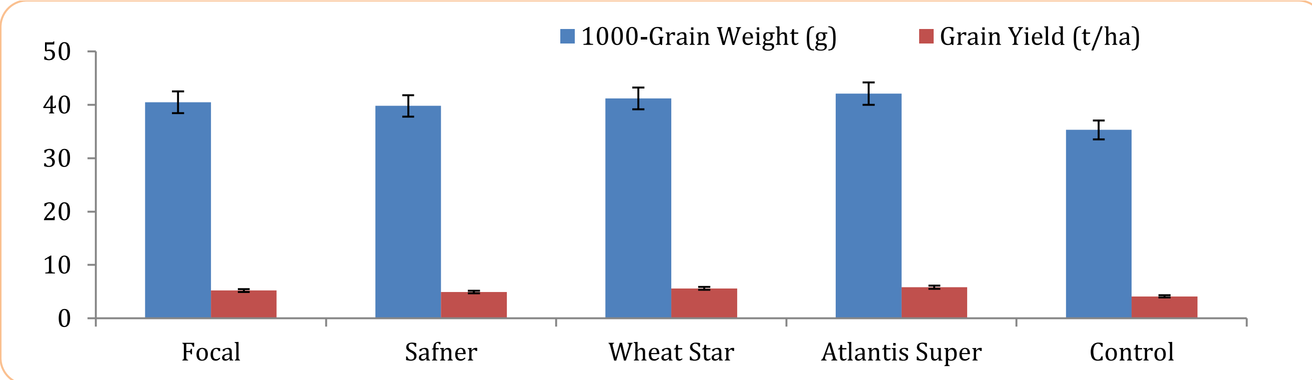

Figure 3: Effect of treatments on 1000-grain weight and grain yield.

Weed control efficiency (WCE)

The calculations of WCE in Figure 4 showed that Atlantis Super had the highest WCE of 79.6%, making it the most effective in suppressing the increase in weed density. Wheat Star and Focal also demonstrated relatively high efficiencies of 76.4% and 72.7%, respectively. Safner was effective as well but had a comparatively lower WCE of 66.8%. These results highlight the varying effectiveness of different herbicide treatments in controlling weeds and improving crop conditions.

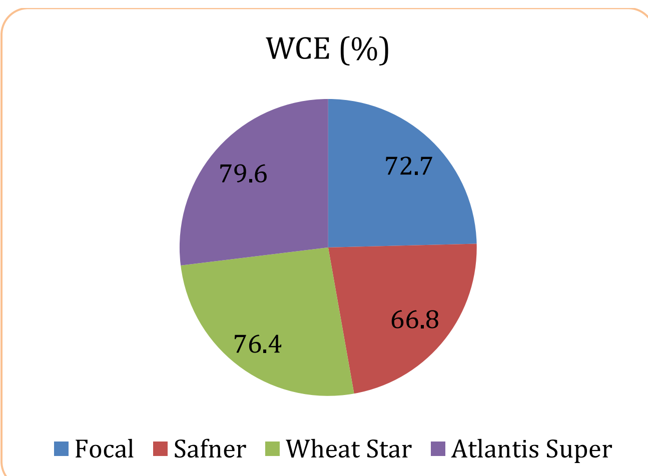

Figure 4: Weed control efficiency (WCE) for each treatment.

DISCUSSION

The significant decline in weed density and biomass with herbicide treatment underscores the vital role of chemical weed management in enhancing crop performance. The lowest weed density (9.3 plants/m^2) and biomass (100 g/m^2) were recorded with the application of Atlantis Super. These results align with earlier studies highlighting the high efficacy of sulfosulfuron-based herbicides in reducing weed pressure (Oreja et al., 2021; Masson et al., 2024). Wheat Star and Focal also demonstrated strong efficacy, illustrating the adaptability of selective herbicides across various agronomic contexts.

Conversely, the lower efficacy of Safner, which resulted in a weed density of 15.2 plants/m^2, suggests that herbicide performance was variable. This variation could be attributed to differences in weed species composition and herbicide mode of action (Brankov et al., 2021).

The untreated control, with the highest weed density (45.7 plants/m^2) and biomass (520 g/m^2), demonstrates that weeds gain a competitive advantage in the absence of management interventions, ultimately leading to yield reduction (Bibi et al., 2008; Asad et al., 2017).

Herbicide treatments significantly improved crop growth and yield parameters, highlighting their dual function in weed control and crop promotion. The fact that Atlantis Super produced the tallest plants (97.3 cm) and the highest number of tillers per plant (7.8) supports its superior weed control efficiency. Similar findings were reported by Cedergreen (2008), who observed increased plant vigor in herbicide-treated plots due to reduced competition for nutrients and light.

The significant increases in yield components, 1000-grain weight and grain yield, further indicate the effect of herbicides. Atlantis Super recorded the highest grain yield of 5.8 t/ha, followed by Wheat Star of 5.6 t/ha and Focal of 5.2 t/ha, whereas the control, which received no chemical treatment, yielded only 4.1 t/ha. The present findings are supported by Mekonnen (2022), who highlights the link between effective weed management and crop productivity enhancement. These differences may be attributed to variations in herbicide formulations and their selective impact on specific weed species (Gopal et al., 2017).

The calculated WCE indicates variation in the effectiveness of herbicide treatments. Atlantis Super emerged as the most potent herbicide, with a high WCE value of 79.6%. Wheat Star and Focal also demonstrated high efficiencies, recording WCE values of 76.4% and 72.7%, respectively, emphasizing the importance of selecting effective herbicides for optimal weed management. The relatively lower WCE value of Safner (66.8%) suggests the need for further evaluation of its performance under different environmental and agronomic conditions (Abbas et al., 2021; Didace et al., 2023).

Long-term herbicide use can lead to the accumulation of residues that may affect soil microbial activity and groundwater quality. Highly water-soluble herbicides, such as mesosulfuron-methyl, may leach into groundwater, necessitating careful management to minimize environmental contamination (Hossain et al., 2022).

Overall, the results highlight the potential for mitigating weed interference and improving crop performance through the strategic application of herbicides with high weed control efficacy (WCE). However, this approach may lead to a reliance on chemical control, increasing the risk of herbicide resistance. Therefore, an integrated approach that incorporates cultural and mechanical practices, as suggested by Mustari et al. (2014), is essential. Future research should focus on the long-term effects of herbicide use on soil health and weed resistance.

CONCLUSION

The application of herbicides in the rice-wheat cropping system is crucial for effective weed management and enhanced crop productivity. Among the tested herbicides, Atlantis Super proved superior in reducing weed density and biomass while improving yield parameters, making it a promising weed control strategy. However, reliance on chemical weed control poses risks, including herbicide resistance and environmental degradation. Therefore, integrated weed management, combining chemical, cultural, and mechanical methods, is essential for sustainable agricultural productivity.

AUTHORS' CONTRIBUTIONS

MJ, SU, SMA, and MAA conceived the idea and participated in the experimental design and supervision of the fieldwork; SHK, GMA, MM, and SB conducted the practical work; MJ and SU performed the data analysis, drafted the manuscript, and revised it; All authors reviewed and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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