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Leveraging Wheat Competition to Manage Seasonal Expansion of Feathertop Rhodes Grass (*Chloris virgata*)

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Abstract: Utilizing the potential of crops to suppress weeds is an important strategy for sustainable management. Feathertop Rhodes grass (FTR) (*Chloris virgata* Sw.) is a problematic warm-season weed in Australia that has recently expanded into colder seasons. This study investigated the growth and seed production of FTR at two planting times (May and July) and three wheat planting densities (0, 82, and 164 plants m^{-2}) using a neighborhood design over two years. In both years, the plant height, tiller production, and panicle production of FTR were lower in the presence of wheat compared to when wheat was absent. Surrounding FTR with wheat delayed its pinnacle emergence, varying from 1 to 6 days in the first year and 4 to 21 days in the second year, depending on the planting date and wheat density. During both years and planting times, wheat's presence caused approximately a 99% decrease in the dry matter and seed production of FTR compared to wheat's absence. Additionally, the wheat height, an important competitive factor, was higher at both densities in the May planting compared to the July planting. The emergence, establishment, and continuous production of FTR seeds throughout the year indicate that inadequate management could result in the further spread of this weed. Our findings suggest that adjusting the date and density of wheat planting could be a viable strategy for sustainably managing this weed during colder seasons.

Keywords: neighborhood design; panicle; planting date; planting density; warm-season weed

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1. Introduction

Weeds are a significant problem in various global cropping systems, impeding agricultural productivity and sustainability. Feathertop Rhodes grass (FTR) (*Chloris virgata* Sw.) is a prevalent warm-season annual weed from the Poaceae family in Australia, posing a significant challenge in fields and pastures [1,2]. FTR exhibits fast growth and prolific seed production, making it highly competitive in agricultural systems. This species can produce over 600 g m^{-2} of dry matter and over 40,000 seeds plant^{-1} [3]. In fallow conditions, this weed can produce over 140,000 seeds plant^{-1} [4]. Significant seed production, combined with a short seed dormancy period and rapid germination, allows FTR to emerge quickly after rainfall in different seasons.

FTR competes with field crops due to its widespread distribution [5]. It has been reported in summer crops, such as mung bean (*Vigna radiata* (L.) Wilczek), sorghum (*Sorghum bicolor* L. Moench), and cotton (*Gossypium hirsutum* L.), grown across subtropical Australia [6,7]. In Australia, FTR has developed resistance to glyphosate, a widely used herbicide. Chauhan and Mahajan [7] confirm this resistance, while Ngo et al. [1] attribute it to target-site EPSPS mutations in the species. Therefore, managing this weed will become more challenging in the future due to its glyphosate resistance, ultimately reducing the herbicide's efficacy.

FTR seeds can germinate across a broad temperature range, from 5 to 40 °C [5,8]. This adaptability allows successful germination in varying environmental conditions, showcasing the seeds' resilience and versatility. FTR grows in tropical, subtropical, and warm temperate areas, and it can also thrive in temperate regions with frequent hot summers [6,7]. The adaptability of weeds like FTR to various climates underscores their ability to thrive and propagate in diverse environmental conditions. A concerning issue regarding FTR is that anecdotal evidence in recent years shows that it has been observed not only in spring and summer but also in cold seasons (May to August) in some areas of Australia.

Since FTR has not been confirmed as a winter weed, there are currently no effective herbicide options available for controlling it during this season. One effective way to manage weeds in crops is through crop interference. Crop interference involves using the crop itself to suppress weed growth by outcompeting them for resources [9]. This technique allows the planted crop to establish dominance over the weeds, reducing their ability to thrive and reproduce in the crop's vicinity. This method offers both economic and environmental advantages, as it decreases the need for herbicides while enhancing the crop's yield and overall quality. Utilizing the crop density is an effective strategy for reducing the growth of weeds such as FTR in a wheat crop [9,10]. By increasing the density of wheat plants, they can compete more effectively for resources like sunlight, water, and nutrients, thereby limiting the access of FTR to these essential components. Additionally, the faster growth rate of wheat compared to FTR further intensifies the competition for these resources, giving the wheat plants a competitive edge. Adjusting crop spacing can optimize light interception and canopy closure, reducing weed seed germination and growth. As mentioned, interference strategies can reduce weed pressure and improve crop yield. For instance, increasing the maize (*Zea mays* L.) density enhanced its competitiveness with weeds, reducing the grain yield losses due to high weed pressure from 26% to 13% as the plant density increased from 4 to 10 plants m^{-2} [10]. Since the ability of wheat to suppress weeds can be significantly influenced by the planting design [11], we predict that wheat can suppress FTR. This study investigates FTR suppression by adjusting the wheat planting density using a neighborhood design, as well as the intraspecific competition of wheat at two different planting densities.

2. Materials and Methods

2.1. Seed Collection and Planting

Seeds of FTR were collected in April 2017 from a sorghum field in Cecil Plains, Queensland, Australia. Seeds were collected from at least 50 plants and stored in plastic containers at room temperature (~25 °C). In the summer season of 2019–2020, the seeds were planted in pots with a diameter of 20 cm, and the plants were grown in an open environment at the Research Farm of the University of Queensland in QLD, Australia. Seeds produced from these plants were used in the current study. Mature seeds were separated from other materials by shaking the plants over a tray and then selected for the study. Wheat (cv. spitfire) seeds were purchased from a commercial supplier. Seeds of both species were planted in plastic pots (25 cm in diameter) filled with commercial potting mix (Centenary Landscaping, Mount Ommaney, Queensland) in 2021 and 2023. The pots were placed on benches in the open at the Gatton Research Farm, University of Queensland, QLD, Australia. The plants were irrigated using a sprinkler system thrice a day for 10 min, but no fertilizer was applied.

2.2. Experimentation and Data Collection

Seeds were planted in May (early winter) and July (late winter) in both years. In 2021, these planting dates resulted in harvests in October and November, respectively. In 2023, they were harvested in mid- and late October, respectively. A neighborhood design was used to evaluate the ability of wheat to suppress FTR. In this design, FTR was planted in the center and surrounded by wheat (0, 4, and 8 plants pot^{-1}; equivalent to 0, 82, and 164 plants m^{-2}).

The plants were harvested when a quarter of the panicles had begun to shed seeds. The recorded attributes of FTR included the plant height (measured from the surface to the tip of the uppermost leaf or panicle), number of tillers, number of panicles, plant dry matter, and number of seeds per plant. The dry matter of surviving plants was obtained by cutting them at the base with secateurs and placing them in paper bags. The samples were dried in an oven at 70 °C for 72 h. The recorded attributes of wheat included the plant height, spike weight, and plant dry matter. The daily maximum and minimum temperatures were obtained from the Gatton Bureau of Meteorology Weather Station near the experimental site (Figure 1).

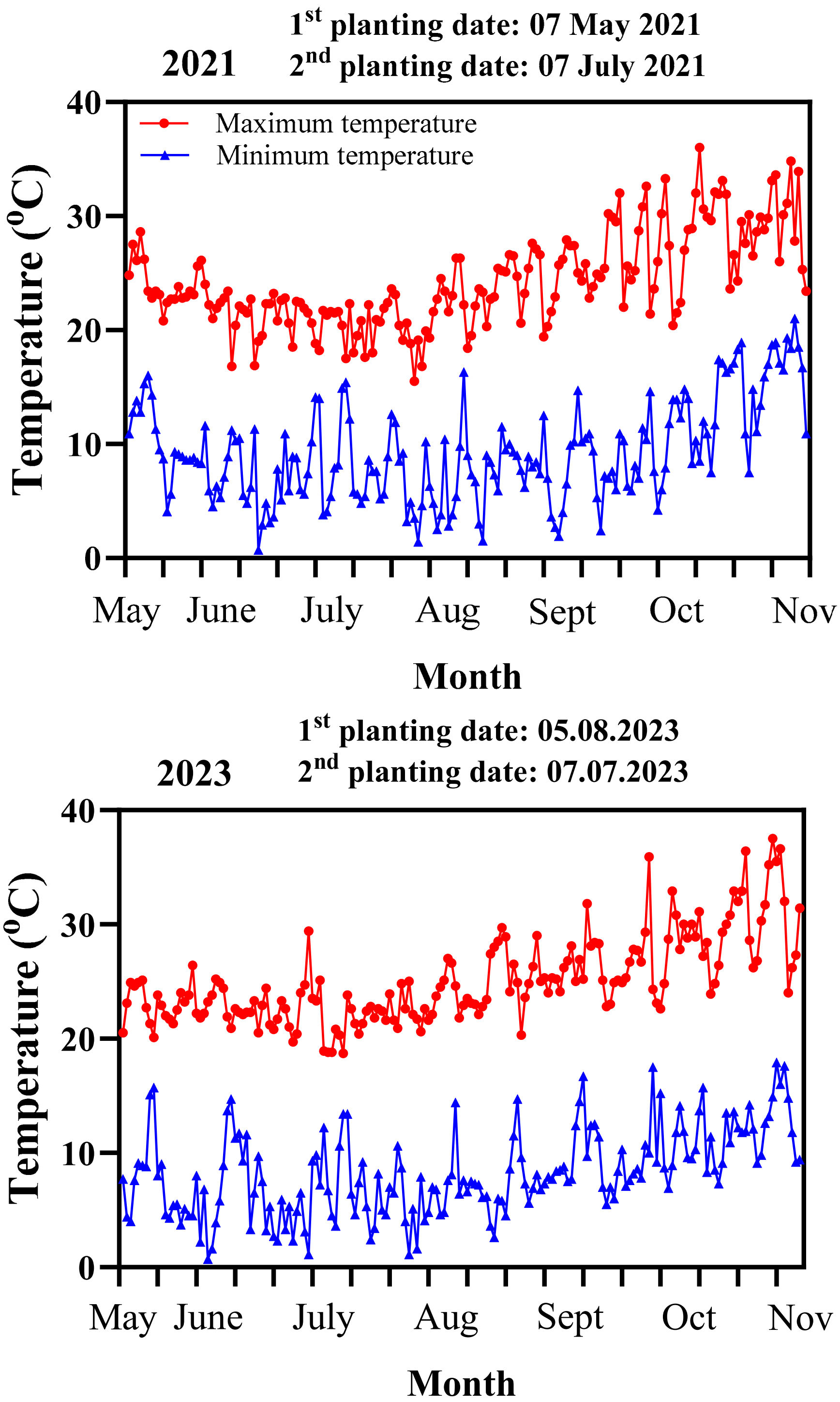

Figure 1. The minimum and maximum daily air temperatures at the study site in 2021 and 2023.

2.3. Statistical Analyses

All the experiments were conducted using a factorial (planting date × wheat planting density) randomized block design with 10 replications each year. The normality and homogeneity of variance of the dataset were assessed using the Shapiro–Wilk test and Levene's test, respectively, before conducting an ANOVA. Data transformation was not necessary. Due to the significant year effects ($p < 0.05$), the data were analyzed separately for each year. The data analysis was conducted using Minitab 17 software (Minitab Inc., State College, PA, USA), and the means were compared using Fisher's least significant difference (LSD) test at a 5% probability level. Graphs of the mean comparisons were generated using GraphPad Prism software (version 10.1.1; GraphPad, San Diego, CA, USA).

3. Results

3.1. Characteristics of FTR

3.1.1. Plant Height

In both years, the height of FTR in May and July was higher in the absence of wheat compared to when wheat was present. In May 2021, wheat densities of 82 and 164 plants m^{-2} resulted in a 77% decrease in the FTR height compared to the absence of wheat (Table 1). The reduction in height for the July planting at these densities was 82% and 91%, respectively. In the May 2023 planting, wheat densities of 82 and 164 plants m^{-2} resulted in a 90% reduction in the FTR height compared to the absence of wheat (Table 1). The reduction in height for the July planting at these densities was 56% and 72%, respectively.

Table 1. The effect of the wheat planting density on the growth and seed production of Feathertop Rhodes grass for the May and July plantings in 2021 and 2023.

Planting Date (Month)	Wheat Planting Density † (Plant m^{-2})	Plant Height (cm)	Tiller Production (No. Plant^{-1})	Panicle Production (No. Plant^{-1})	Dry Matter (g Plant^{-1})	Seed Production (No. Plant^{-1})
2021						
May ‡	0	48.8 ± 0.96 b	158.7 ± 7.61 a	259.3 ± 16.07 a	43.04 ± 1.80 a	67,678 ± 3866 a
	82	10.9 ± 1.39 c	2.5 ± 0.27 c	4.2 ± 0.73 c	0.07 ± 0.01 c	219 ± 56 c
	164	11.8 ± 1.39 c	2.0 ± 0.42 c	5.1 ± 1.19 c	0.05 ± 0.02 c	321 ± 137 c
July	0	63.2 ± 2.16 a	66.1 ± 9.32 b	56.3 ± 9.40 b	25.52 ± 3.74 b	24,151 ± 3637 b
	82	11.1 ± 2.16 c	2.0 ± 0.39 c	2.1 ± 0.50 c	0.05 ± 0.02 c	34 ± 13 c
	164	5.4 ± 1.40 d	0.9 ± 0.18 c	0.7 ± 0.21 c	0.01 ± 0.00 c	9 ± 4 c
2023						
May	0	12.2 ± 5.78 cd	12.1 ± 5.41 b	19.0 ± 7.83 b	7.23 ± 3.08 b	9983 ± 4241 b
	82	1.2 ± 0.49 d	0.7 ± 0.33 c	1.2 ± 0.55 c	0.03 ± 0.02 c	135 ± 119 c
	164	1.2 ± 0.52 d	0.0 ± 0.00 c	0.6 ± 0.27 c	0.01 ± 0.00 c	16 ± 8 c
July	0	58.4 ± 6.61 a	33.5 ± 4.35 a	46.4 ± 5.79 a	22.87 ± 3.04 a	28,479 ± 4077 a
	82	25.9 ± 3.34 b	2.3 ± 0.54 c	3.8 ± 0.73 c	0.37 ± 0.11 c	482 ± 178 c
	164	16.1 ± 4.03 bc	1.0 ± 0.26 c	1.8 ± 0.49 c	0.09 ± 0.03 c	60 ± 18 c

† Planting densities of 0, 82, and 164 plants m^{-2} represent the planting density of wheat in a field, which corresponds to 0, 4, and 8 plants pot^{-1}, respectively. ‡ In Australia, May marks the beginning of the planting season for winter crops, while July signals its end. Values ± standard errors of the mean. Lowercase letters in each column indicate that values with the same letters do not differ significantly at the 0.05 probability level according to the least significant difference (LSD) test.

3.1.2. Tiller and Panicle Production

In May and July 2021, planting densities of 82 and 164 wheat plants m^{-2} resulted in approximately a 98% decrease in tiller production compared to when wheat was absent (Table 1). In May and July 2023, these densities resulted in a 93–100% decrease in tiller production compared to the absence of wheat (Table 1). In both years, May and July plantings with densities of 82 and 164 wheat plants m^{-2} led to a 92–99% decrease in panicle production compared to the absence of wheat (Table 1).

3.1.3. Dry Matter and Seed Production

During both years and both planting times (May and July), the presence of wheat (82 and 164 plants m^{-2}) caused an approximately 99% decrease in FTR dry matter compared to the absence of wheat (Table 1). Additionally, the presence of 82 and 164 wheat plants m^{-2} resulted in an approximately 99% decrease in seed production in FTR compared to the absence of wheat in both the May and July plantings in both years (Table 1).

3.2. Panicle Emergence Time in FTR

Surrounding FTR with wheat delayed the emergence of FTR panicles in both years of the study. In 2021, planting wheat at both densities (82 and 164 plants m^{-2}) delayed FTR panicle emergence for the May (3 to 6 days) and July (1 to 3 days) plantings compared to when wheat was absent (Table 2). Similarly, in 2023, the presence of wheat at both densities delayed FTR panicle emergence for the May (12 to 21 days) and July (4 to 10 days) plantings compared to the absence of wheat (Table 2).

Table 2. The effect of the wheat planting density on the emergence time of Feathertop Rhodes grass (FTR) panicle for the May and July plantings in 2021 and 2023.

Planting Date (Month)	Wheat Planting Density † (Plant m^{-2})	Panicle Emergence Time (DAP)	
		2021	2023
May ‡	0	100 ± 1.2 b	110 ± 1.6 c
	82	106 ± 0.4 a	131 ± 2.0 a
	164	103 ± 0.9 a	122 ± 1.5 b
July	0	81 ± 1.2 d	71 ± 0.6 e
	82	82 ± 0.5 cd	75 ± 0.4 e
	164	84 ± 0.3 c	81 ± 1.6 d

† Planting densities of 0, 82, and 164 plants m^{-2} represent the planting density of wheat in a field, which corresponds to 0, 4, and 8 plants pot^{-1}, respectively. ‡ In Australia, May marks the beginning of the cold season, while July signals its end. DAP: day after planting. Values ± standard errors of the mean. Lowercase letters in each column indicate that values with the same letters do not differ significantly at the 0.05 probability level according to the least significant difference (LSD) test.

3.3. Characteristics of Wheat

In 2021, the height of the wheat was greater at densities of 82 and 164 plants m^{-2} (16% and 24%, respectively) for May compared to the July planting (Figure 2A). In 2023, the height of the wheat planted at 82 and 164 plants m^{-2} for May was 12% and 6% higher, respectively, compared to the July planting (Figure 2B).

In 2021, the interaction between the planting date and planting density on the wheat spike weight was not significant. However, for the May planting, the wheat spike weight was 72% higher compared to the July planting (Figure 2C). Additionally, at a density of 164 wheat plants m^{-2} compared to 82 plants m^{-2}, the wheat spike weight was 28% higher (Figure 2C). For the July planting in 2023, the weight of wheat spikes planted at 164 plants m^{-2} was, on average, approximately 46% higher compared to the other planting densities and planting times (Figure 2D).

For the May 2021 planting, the dry matter of wheat was 25% higher at a density of 164 plants m^{-2} compared to 82 plants m^{-2} (Figure 2E). The dry matter of wheat at the same planting time and density (May and 164 plants m^{-2}) was 66% higher compared to both planting densities for the July planting (Figure 2E). For the July 2023 planting, the dry matter of wheat planted at 164 plants m^{-2} was, on average, 45% higher compared to the other planting densities and planting times (Figure 2F).

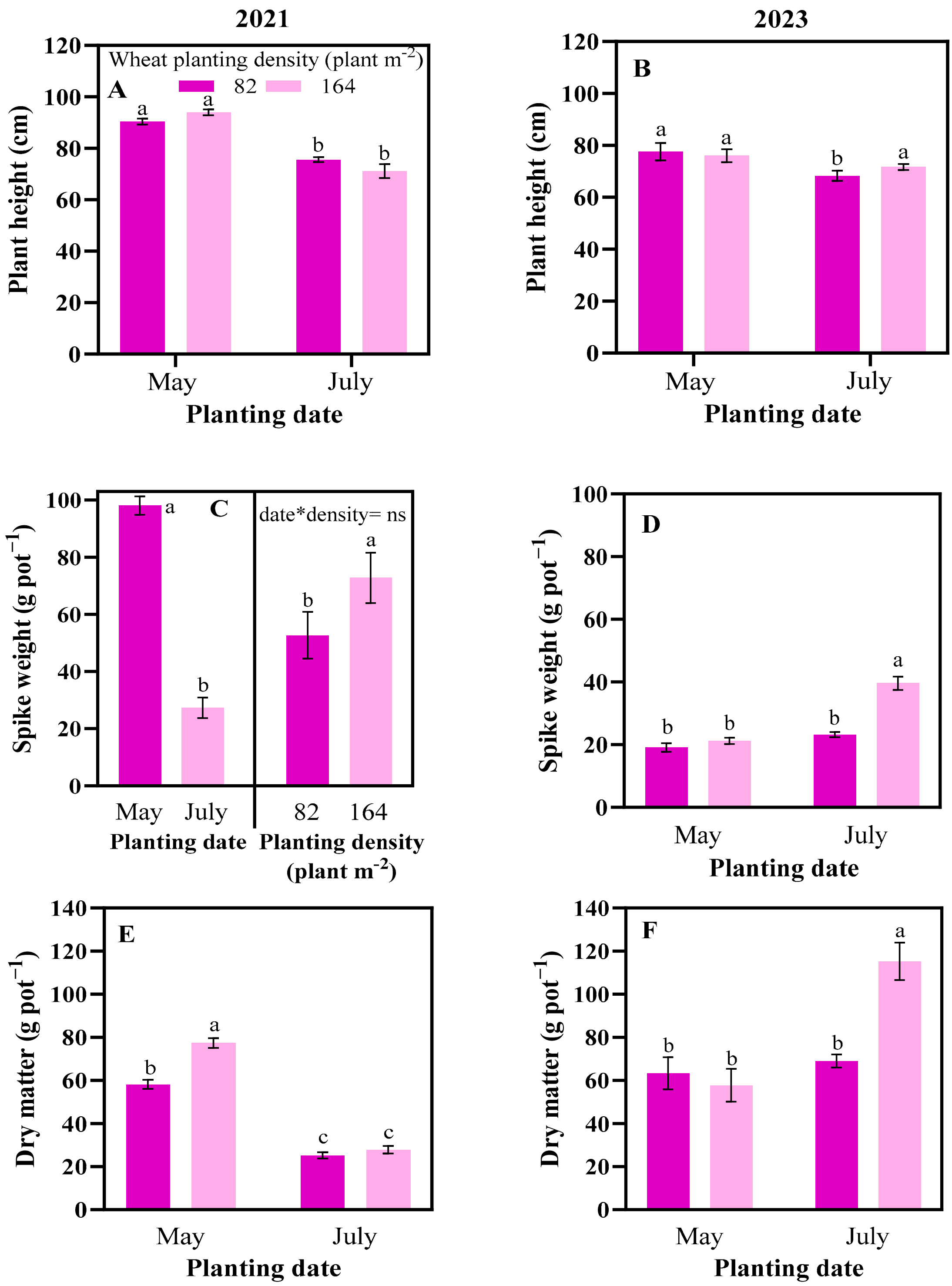

Figure 2. The effect of the planting density on the plant height (**A**,**B**), spike weight (**D**), and dry matter (**E**,**F**) of wheat for the May and July plantings in 2021 and 2023. The interaction effect of the planting date and planting density on the wheat spike weight in 2021 was not significant. The figure illustrates the main effects of each factor (**C**). The error bars represent the standard error of the mean. Bars with the same letters indicate no significant differences according to the LSD at $p \leq 0.05$.

4. Discussion

Increasing the crop density can lead to competition for resources such as sunlight, water, and nutrients, which suppresses weed growth [12]. In our study, the presence of wheat around FTR reduced the growth characteristics of this weed (Table 1). The significant decrease in FTR height in the presence of wheat for both the May and July plantings indicates wheat's high competitiveness. The faster growth of wheat compared to FTR likely led to more absorption of sunlight for photosynthesis, resulting in more effective utilization of resources such as water and nutrients [11,13]. Therefore, the plant height can be a significant factor in determining the competitive success of weeds in a specific ecosystem.

Suppressive crops reduce the tiller and panicle production in weeds by creating a dense canopy that shades out the weeds, preventing their establishment and seed production. Previous studies have shown that the potential for tiller and panicle production in weeds is related to the competitiveness of wheat [11,14]. In the present study, FTR surrounded by wheat showed decreased growth characteristics, such as tiller and panicle production. In 2021, the absence of wheat for May compared to the July planting led to 2.4 times higher tiller production and 4.6 times higher panicle production (Table 1). Early planting and a longer growing season for May compared to the July planting likely provided more opportunities for plant development, resulting in higher tiller and panicle production in the FTR planted in May. Conversely, in 2023, plants planted in July had 2.8 and 2.4 times more tillers and panicles, respectively, compared to those planted in May in the absence of wheat (Table 1). The lower average minimum temperature in 2023 compared to 2021 exposed the plants planted in May (early planting) to cold for a longer duration, reducing their ability to produce tillers and panicles compared to the plants planted in July.

In both years, the time required for panicle emergence was longer for the May planting compared to the July planting (Table 2). The presence of wheat as a suppressive crop delayed the emergence of FTR panicles for both the May and July plantings compared to its absence. The deprivation of essential resources, such as sunlight, water, and nutrients, due to the competitive advantage of the wheat crop leads to significant disruption of various biochemical and physiological processes within the FTR plant. These disruptions include the production of crucial enzymes and hormones necessary for the emergence of panicles, which are vital for the reproductive success of the weed. This growth delay enabled wheat to outperform FTR in terms of suppression. Similarly, competition from pasture plants has been reported to increase weed mortality, reduce establishment rates, and delay weed growth [15].

Our study clearly showed that wheat planting at the mentioned densities can significantly hinder FTR growth, dry matter, and seed production. The interaction between wheat and FTR likely reduced the weed dry matter through competition for resources like water and nutrients. Well-established and actively growing crops can outcompete weeds for resources, limiting the growth and development of weeds and ultimately reducing their dry matter [16]. Kim and Chauhan [17] reported that lablab (*Lablab purpureus*) displayed the highest competitiveness among the studied broadleaf and grass species, causing a minimum 99% decrease in the Navua sedge (*Cyperus aromaticus*) dry biomass. Wheat's potential release of chemicals [18], known as allelochemicals, could also slow down FTR growth. Additionally, wheat creates a dense canopy that physically blocks sunlight from reaching FTR, limiting its photosynthetic activity and growth. FTR is a summer plant by nature, so the temperatures during the planting seasons were more favorable for wheat seed germination and growth compared to FTR. As a result, the transfer of photosynthetic materials from the source (leaves) to the sink (seeds) in wheat was likely faster than in FTR, contributing to an overall increase in the wheat biomass accumulation and suppression potential.

Early planting in May, compared to late planting in July, was a determining factor for growth, dry matter production, and seed production in 2021. In the absence of wheat, planting in May resulted in significantly higher production of dry matter and seeds compared to planting in July. The higher dry matter and seed production in FTR in the absence of wheat for the July 2023 planting compared to the May planting (Table 1) can be attributed to the lower temperatures during the growth period of the plants planted in May and the death of some of them.

The crop height is one of the most important factors influencing competitiveness with weeds [19]. A taller crop absorbs more sunlight for photosynthesis, promoting increased growth. Additionally, taller crops typically develop deeper roots, enhancing their capacity to outcompete weeds for water and nutrients in the soil [20,21]. In the first year, the height of wheat, regardless of the density, was eight and nine times higher than the height of FTR for the May and July plantings, respectively. In the second year, the mentioned values for the May and July plantings were 64 and 3 times higher than the FTR height. The rapid growth rate of wheat seedlings and their better growth potential in cold seasons compared to FTR as a summer weed contributed to its greater height. Wheat, with its advantage in terms of light exposure, space, and resources, clearly acted as a suppressive crop, significantly reducing FTR growth and seed production. The noticeable decrease in the FTR height and other characteristics for the May planting in the second year was due to the lower temperatures and FTR's lack of proper adaptation to the environmental conditions. Increasing the wheat planting density from 82 to 164 plants m^{-2} did not adversely affect the wheat growth characteristics, suggesting the absence of intraspecies competition among wheat plants. Other studies also indicate that wheat is more competitive compared to some crop species and weeds. Wheat has been found to be more competitive than wild oat (*Avena sterilis* subsp. *ludoviciana*), chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), and canola (*Brassica napus* L.) [22,23]. According to similar studies, favorable growth characteristics such as the plant height, leaf area, tillering capacity, and biomass accumulation rate contribute to wheat's ability to suppress weeds [24]. For instance, Balyan et al. [22] observed a negative correlation between the winter wheat dry matter accumulation and the grain yield with wild oat dry matter.

5. Conclusions

FTR is typically considered a summer weed, and its presence in colder seasons may be overlooked, or conventional control methods may be ineffective. Consequently, its wide distribution to other regions is predicted due to its ability to germinate and adapt to a wide range of temperatures. Our study demonstrated that autumn planting of wheat significantly reduced FTR growth and seed production, effectively acting as a suppressive plant in competition with this weed. Therefore, adjusting the timing and density of wheat planting can decrease the presence and spread of FTR, promoting sustainable production practices. This practice promotes sustainable agriculture by minimizing the use of chemical herbicides while maintaining crop productivity. Ultimately, it reduces the potential environmental impacts associated with conventional weed control methods.

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