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RESEARCH ARTICLE

Evaluation of the competitive ability of four wheat (*Triticum aestivum* L.) cultivars with weeds and its effect on growth characteristics, yield and its components

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Abstract

A field experiment was conducted at the Abu Ghraib Research Station during the 2022 and 2023 seasons using a split-plot experiment laid out in a randomized complete block design (RCBD) with three replications. The study aimed to assess the competitive ability of four wheat cultivars (Buhuth 22, Buhuth 10, Baghdad and Ibaa 99) against weeds and their effects on growth traits, yield and its components. The experiment included four weed competition treatments: complete weed removal, removal of narrow-leaved weeds, removal of broad-leaved weeds and no weed removal. The results showed that weed removal improved all studied traits, with the weed-free treatment recording the highest plant height (92.0 cm), number of spikes (407.1 spikes m^{-2}), 1000-grain weight (38.95 g) and grain yield (6.33 tons ha^{-1}). In contrast, full weed competition led to a reduction in these values by up to 45 %. The Buhuth 22 cultivar outperformed others in most yield traits, recording the highest grain yield (5.52 tons ha^{-1}), whereas Buhuth 10 had the lowest productivity (3.71 tons ha^{-1}). Additionally, cultivars with rapid growth and high density exhibited greater competitiveness against weeds, minimizing their negative impact on growth and productivity. The removal of either narrow- or broad-leaved weeds had a similar effect in reducing competition and enhancing growth, though the completely weed-free treatment achieved the best results. The study recommends adopting highly competitive cultivars such as Buhuth 22 and enhancing weed control through dense planting and integrated management practices. This combined strategy promotes sustainable wheat productivity, minimizes herbicide dependence and ensures efficient resource utilization for achieving high yields under weed-infested conditions.

Keywords: integrated weed management; sustainable wheat production; weed interference; wheat cultivar competitiveness; yield component

Introduction

Wheat (*Triticum aestivum* L.) cultivation in Iraq faces significant challenges due to climatic variability, such as declining rainfall, alongside shifts in agricultural policies and irrigation practices, all of which contribute to production instability. According to 2023 data, Iraq's total wheat cultivation area was approximately 842000 hectares, producing 4248000 tons-an average yield of 5.05 tons per hectare (1). In comparison, developed countries like the United States and Canada report yields ranging from 6 to 7 tons ha^{-1} disparity largely attributed to the implementation of advanced agricultural technologies. These include modern irrigation systems, improved wheat cultivars and integrated crop management practices (2). Despite its strategic importance for food security, wheat productivity in Iraq is significantly hindered by weed competition. Different wheat varieties vary in their ability to suppress or resist weeds, highlighting the importance of research focused on understanding these varietal differences and their impact on yield. The lack of accurate data on the competitive ability of various wheat cultivars remains a major obstacle to designing effective agricultural strategies. Although herbicides are commonly used to manage weeds, their excessive application may not be economically sustainable and could lead to environmental degradation, underscoring the need for more sustainable weed control approaches.

Wheat is one of the most widely cultivated cereal crops, providing a major share of global caloric and protein intake. Its adaptability across diverse climates and soils has made it a cornerstone of agricultural systems worldwide. Beyond its nutritional importance, wheat sustains rural economies and food industries. Nevertheless, its productivity remains vulnerable to biotic and abiotic stresses, particularly weed competition, which significantly reduces yield potential (3). However, its cultivation is hindered by various environmental challenges that adversely affect growth and yield. Among these, weed competition stands out as a major constraint on agricultural productivity. Weeds compete with wheat for critical resources such as water, light and nutrients, ultimately resulting in impaired plant development and decreased production efficiency (4, 5).

This study is vital for enhancing wheat productivity in the face of Iraq's environmental and climatic challenges. It aims to deliver scientific insights into the competitive performance of various wheat varieties against weeds, thereby supporting farmers and policymakers in identifying the most suitable cultivars for local agricultural conditions. Moreover, the research seeks to minimize dependence on chemical herbicides, fostering sustainable farming practices that benefit both producers and the broader agricultural sector (6).

This study aims to evaluate the competitive ability of four wheat varieties (*T. aestivum* L.) against weeds, focusing on the impact of weed interference on growth traits and yield components. The primary objective is to generate practical, science -based recommendations for effective weed management and enhanced wheat productivity. By identifying the most weed-tolerant varieties, the research seeks to strengthen agricultural sustainability while reducing dependence on chemical herbicides (7).

A split-plot experimental design was employed to assess the performance of the four wheat varieties under controlled agricultural conditions. Key growth parameters and yield attributes were recorded and statistical analyses were conducted to compare varietal responses. The findings provide data-driven insights that can guide improved cultivation practices and support the development of sustainable weed management strategies.

This study fills the research gap by evaluating the competitive ability of four wheat (*T. aestivum* L.) cultivars under different weed interference patterns, using a randomized complete block design (RCBD) arranged in a split-plot layout. The findings highlight the most tolerant cultivars and provide science-based recommendations to enhance wheat productivity sustainably while reducing dependence on herbicides.

Materials and Methods

Wheat (*T. aestivum* L.) is a staple cereal crop of global importance, serving as a key dietary component and playing a vital role in global food security. However, its cultivation is hindered by various environmental challenges that adversely affect growth and yield. Among these, weed competition stands out as a major constraint on agricultural productivity. Weeds compete with wheat for critical resources such as water, light and nutrients, ultimately resulting in impaired plant development and decreased production efficiency (8, 9).

Wheat cultivation in Iraq faces significant challenges due to climatic variability, such as declining rainfall, alongside shifts in agricultural policies and irrigation practices, all of which contribute to production instability. According to 2023 data, Iraq's total wheat cultivation area was approximately 946400 hectares, yielding 4233714 tons, an average productivity of 1.789 tons per hectare. In comparison, developed countries like the United States and Canada report yields ranging from 6 to 7 tons ha^{-1} disparity largely attributed to the implementation of advanced agricultural technologies. These include modern irrigation systems, improved wheat cultivars and integrated crop management practices. Despite its strategic importance for food security, wheat productivity in Iraq is significantly hindered by weed competition. Different wheat varieties vary in their ability to suppress or resist weeds, highlighting the importance of research focused on understanding these varietal differences and their impact on yield. The lack of accurate data on the competitive ability of various wheat cultivars remains a major obstacle to designing effective agricultural strategies. Although herbicides are commonly used to manage weeds, their excessive application may not be economically sustainable and could lead to environmental degradation, underscoring the need for more sustainable weed control approaches.

This study is vital for enhancing wheat productivity in the face of Iraq's environmental and climatic challenges. It aims to deliver scientific insights into the competitive performance of various wheat varieties against weeds, thereby supporting farmers and policymakers in identifying the most suitable cultivars for local agricultural conditions. Moreover, the research seeks to minimize dependence on chemical herbicides, fostering sustainable farming practices that benefit both producers and the broader agricultural sector.

A field experiment was conducted using a split-plot design within a randomized complete block arrangement to evaluate the response of four modern wheat (*T. aestivum* L.) cultivars under different levels of weed competition (10). Key growth and yield parameters were recorded and statistical analyses were applied to compare cultivar performance. The study aimed to identify competitive cultivars and provide practical recommendations for sustainable wheat production and effective weed management.

The field trial was carried out at the Abu Ghraib Agricultural Research Station, incorporating various weed competition treatments. Main plots: FW (Free Weed): Weed-free treatment (complete weed removal throughout the season). NW (Narrow-leaved Weeds): Treatment with narrow-leaved weeds (removal of broad-leaved weeds only). BW (Broad-leaved Weeds): Treatment with broad-leaved weeds (removal of narrow-leaved weeds only). W (Weedy): Fully weed-infested treatment (no weed removal, allowing full competition). Wheat cultivars (sub-plots: (Buhuth 22, Buhuth 10, Baghdad and Ibaa 99)) (Table 1).

Sowing was carried out on November 15 for both seasons, following the local cropping season, with a fixed seeding rate of 140 kg ha^{-1} (11, 12). All agricultural practices were uniformly applied to all experimental units to ensure a suitable growth environment, including (i) Land preparation: ploughing and levelling to create optimal conditions for plant growth (1, 8); (ii) Sowing: conducted in rows of 1 m length with 20 cm spacing between rows (13); (iii) Fertilization: application of 150 kg/ha^{-1} of DAP fertilizer (as a phosphorus source) and 200 kg/ha^{-1} of urea fertilizer (as a nitrogen source). Fertilizers were applied in split doses throughout the growing season to enhance nutrient absorption; (iv) Irrigation: conducted based on local climatic conditions and crop water requirements to ensure sustainable growth (14).

A set of morphological and productive traits of the plant were evaluated, including:

1. Weed density (plant m^{-1})
2. Weed control percent (%)

Table 1. Names of weeds scattered in the experiment

English name	Scientific name	Family	Life cycle
Narrow-leaves weeds			
Johnson grass	*Sorghum halepense* L.	Poaceae	Perennial
Rigidry grass	*Lolium rigidum* L.	Poaceae	Annual
Lesser canary	*Phalaris minor* L.	Poaceae	Annual
Wild oat	*Avena fatua* L.	Poaceae	Annual
Nutgrass	*Cyperus rotundus* L.	Cyperaceae	Perennial
Broad-leaves weeds			
Button weed	*Malva rotundifolia* L.	Malvaceae	Annual
Common Bishop's weed	*Ammi majus* L.	Umbiliferae	Annual
Field Bind Weed	*Convolvulus arvensis* L.	Convolvulacea	Perennial
Milk thistle	*Silybum marianum* L.	Compositae	Annual
Purslane	*Portulaca oleracea* L.	Portulacaceae	Annual
Wild safflower	*Carthamus oxyacanthus*	Compositae	Annual
White goosefoot	*Chenopodium album* L.	Chenopodiaceae	Annual
Wild beets	*Beta vulgaris* L.	Plantaginaceae	Annual

3. Dry weight of the weeds (gm m^{-1})
4. Inhibition (%)
5. Plant height (cm)
6. Number of spikes (m^{-2})
7. Number of grains ($spike^{-1}$)
8. Weight of 1000 grains (g)
9. Grain yield (tons ha^{-1})
10. Biological yield (tons ha^{-1})
11. Spike length (cm)

Statistical analysis

The field experiment was conducted using a RCBD in a split-plot arrangement and three replications. This design was selected to minimize environmental variability across blocks and to facilitate the evaluation of two experimental factors: wheat cultivars and weed competition levels. Data were periodically collected and subjected to analysis of variance (ANOVA) to assess the effects of weed competition and varietal differences on crop growth and productivity. Treatment means were compared using the Least Significant Difference (LSD) test at the appropriate significance level to identify significant variations among treatments (15, 16).

Results and Discussion

Weed density (plant m^{-2})

The manual removal of narrow- and broad-leaved weeds is an effective method to reduce their density within the unit area in wheat fields, thereby limiting their competition with the crop for natural resources such as light, water and nutrients (17). Studies indicate that the presence of untreated weeds can lead to a reduction in wheat yield by up to 45 % (18). As shown in Table 2, the untreated weed treatment (weedy) recorded the highest weed density, reaching (60.17 and 69.75 plants m^{-2}) over two consecutive years. In contrast, treatments for removing either broad-leaved or narrow-leaved weeds did not show significant differences between them during the same period.

Wheat cultivars also differ in their effect on weed density within the unit area. Cultivars with dense growth and a wide leaf canopy are more effective in reducing weed density compared to others due to their enhanced competition for essential resources. According to the source grain Crop Production, data showed that the weed density associated with the IPA99 cultivar reached (34.92 and 39.67 plants m^{-2}) over two years, significantly outperforming other cultivars.

Research has shown that the interaction between weed removal treatments and different wheat cultivars at the same plant density significantly affects weed density. Weed density decreases more effectively when early weed removal is combined with the cultivation of highly competitive cultivars. These findings emphasize the importance of selecting the appropriate cultivar alongside proper weed removal timing to minimize their negative impact. According to Weed Management in Agricultural Crops the highest weed density was recorded in the untreated weed treatment with the IPA99 cultivar, reaching (83.33 and 91.33 plants m^{-2}) over two consecutive years compared to the weed removal treatment. This is attributed to the strong growth characteristics and productivity of this cultivar, such as plant height, the number of spikes and grain weight, which enhance its competitive ability against weeds. However, available sources do not provide specific details on this cultivar's weed resistance.

Weed control percent (%)

Studies indicate that manual weed removal, whether for narrow-leaved or broad-leaved weeds, significantly impacts control effectiveness in a field experiment, it was found that manual hoeing led to a reduction in weed density and an increase in crop productivity.

According to the data presented in Table 3, the weed percentage in the Free Weedy treatment reached 100 %, compared to the Broad Weed and Narrow Weed treatments, which showed

Table 2. Weed density (plant m^{-2})

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	IPA99	Mean	Bo_{10}	Bo_{22}	Baghdad	IPA99	Mean
BW	25.67	20.00	29.67	28.33	25.92	31.67	24.33	38.67	33.67	32.08
NW	27.67	21.00	28.67	28.00	26.33	32.00	25.33	34.67	33.67	31.42
FW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W	41.33	68.67	47.33	83.33	60.17	52.33	79.33	56.00	91.33	69.75
Mean	23.67	27.42	26.42	34.92	28.10	29.00	32.25	32.33	39.67	33.31
LSD ≤ 0.05	Weeds 1.991		Varieties 3.776	W.T. × V 6.715		Weeds 2.078		Varieties 2.102	W.T. × V 3.998	

Table 3. Weed control percent (%)

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	IPA99	Mean	Bo_{10}	Bo_{22}	Baghdad	IPA99	Mean
BW	37.25	70.64	37.53	66.07	52.87	39.38	69.36	30.86	63.07	50.67
NW	31.75	69.11	38.72	66.39	51.49	38.61	68.08	38.15	63.10	51.98
FW	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	42.25	59.94	44.06	58.11	51.09	44.50	59.36	42.25	56.54	50.66
LSD ≤ 0.05	Weeds 2.630		Varieties 4.656	W.T. × V 8.313		Weeds 2.827		Varieties 3.024	W.T. × V 5.695	

significantly lower growth rates compared to the untreated treatment (19).

Regarding the varieties, the Bo22 variety demonstrated a highly competitive ability against weeds during both study seasons, compared to the IPA99 variety, which recorded the highest weed growth percentage over the two seasons.

As for the interaction between varieties and weed types, it was observed that the Bo22 variety, when broadleaf weeds were removed, recorded the highest weed growth percentage over the two seasons, compared to the Bo10 variety, which achieved the lowest weed growth rate over the two consecutive seasons.

Dry weight of the weeds (g m^{-2})

Table 4 shows that broad weeds (Broad w.) recorded the highest average weight of 73.0 g m^{-2}, while the narrow weed removal treatment (Narrow w.) had a relatively lower average weight of 49.3 g m^{-2} (8). As for the weedy areas (Weedy), they recorded the highest values, with an average of 244.4 g m^{-2}, indicating the significant impact of weed density in these areas (20). Regarding the second year of the study, the results were similar to those recorded in the first year, with a slight increase that was not statistically significant.

Concerning the effect of the varieties factor (Varieties), the results over both years showed that the IPA99 variety recorded the highest weed weight values when broad weeds were removed, reflecting its high sensitivity to their presence. In contrast, the "Baghdad" variety recorded the lowest weed weight values in most treatments, suggesting a certain level of resistance. The data also indicate that the EBAA variety represents an outlier, especially in the case of broad weeds, necessitating further studies to understand this behaviour (21). Notably, the absence of weights in the weed-free field (Free weed) is natural and expected due to the lack of weeds in this treatment.

Regarding the interaction effect between (Weeds × Varieties), the results revealed a significant difference between broad and narrow weeds, indicating an interaction between weed type and the cultivated variety. This necessitates further research to understand the nature of this interaction and its impact on agricultural productivity.

Inhibition (%)

Table 5 clearly shows that the highest inhibition percentage was recorded in the treatment that was completely free of weeds (Free weed = 100 %) (8), indicating the significant negative impact of weeds on the inhibition process. In contrast, the lowest inhibition percentage was observed in the treatment exposed to weeds (Weedy = 0 %), confirming the intense competitive effect of weeds in this environment (15).

When comparing the results of both years, it was found that the second year followed a similar general trend to the first year, where the Bo10 and Bo22 cultivars exhibited higher inhibition rates compared to the other cultivars, reflecting their superior ability to resist the negative effects of weeds or enhance their internal inhibition mechanisms. Conversely, the Baghdad and EBAA cultivars showed significantly lower inhibition rates compared to Bo10 and Bo22, indicating their weaker inhibition capacity under the studied conditions (22).

Slight increases in the overall performance of the cultivars were also observed during the second year, which could be attributed to improved environmental conditions or increased inhibition efficiency over time.

Regarding the effect of weeds, significant differences were found among weed types, suggesting that some weeds exert a stronger influence on the inhibition process than others. Similarly, cultivars exhibited significant differences in their inhibition

Table 4. Dry weight of the weeds (g m^{-2})

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	62.9	54.4	62.9	111.6	73.0	69.2	59.9	69.2	122.7	80.3
NW	52.4	47.1	56.5	41.3	49.3	57.6	51.8	62.2	45.4	54.2
FW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
W	290.5	295.5	146.6	245.1	244.4	319.5	325.1	161.3	269.6	268.9
Mean	101.5	99.3	66.5	99.5	91.7	111.6	109.2	73.2	109.4	100.8
LSD ≤ 0.05	Weeds 25.98		Varieties 22.22	W.T. × V 43.85		Weeds 9.93		Varieties 6.03	W.T. × V 13.38	

Table 5. Inhibition (%)

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	78.0	81.1	44.6	54.4	64.5	78.33	81.54	56.57	54.45	67.72
NW	81.6	83.6	53.4	83.1	75.5	81.95	84.04	61.46	83.13	77.65
FW	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	64.9	66.2	49.5	59.4	60.0	65.07	66.40	54.51	59.39	61.34
LSD ≤ 0.05	Weeds 9.89		Varieties 9.15	W.T. × V 17.73		Weeds 2.613		Varieties 1.681	W.T. × V 3.639	

responses, with an LSD value of 9.15 for differences among cultivars, confirming the genuine variation in their inhibition abilities.

As for the interaction between weed effects and cultivars, it was statistically significant, with an LSD value of 17.73 in the first year, which decreased to 3.639 in the second year, possibly indicating stabilization of interactions or a reduction in the intensity of effects over time (23).

Plant height (cm)

Table 6 illustrates that the weed removal treatment, whether for broadleaf or narrow leaf weeds, had a significant impact on plant height during both study seasons. This treatment recorded a height of 94.64 cm and 92.00 cm for the first and second seasons, respectively, significantly outperforming all other treatments. In contrast, the weedy treatment (where no weed removal was performed) showed the lowest average plant height, measuring 74.4 cm and 66.13 cm for the two seasons, respectively, indicating the negative impact of weeds in limiting plant growth (19).

Table 6 shows that the Bo22 variety recorded the highest plant height, reaching 98.09 cm and 95.7 cm during the first and second seasons, respectively, significantly surpassing the other varieties. Conversely, the Baghdad variety exhibited the lowest average height, measuring 76.59 cm and 74.69 cm for the two seasons, indicating a clear difference between varieties in their response to growth conditions.

Regarding the interaction between weed treatments and wheat varieties, the weed removal treatment combined with the Bo22 variety recorded the highest plant height, reaching 102.1 cm and 99.87 cm during the two seasons, emphasizing the positive role of weed removal in enhancing the growth of this specific variety. On the other hand, the weedy treatment combined with the EBAA variety recorded the lowest plant height, measuring 68.36 cm and 66.13 cm, with no significant differences compared to the weedy treatment with the Baghdad variety during both seasons (24).

Number of spikes (m^{-2})

Table 7 includes data on the number of spikes per square meter, shows that the weed removal treatment achieved the highest spike count, reaching 400.8 and 407.1 spikes m^{-2} during the first and second seasons, respectively. In contrast, the weedy treatment recorded the lowest rate for this trait, with 263.7 and 281.9 spikes m^{-2} for the same seasons, indicating the negative impact of weeds on spike production (6).

Regarding the varieties, EBAA outperformed all other varieties by achieving the highest spike count, reaching 378.8 and 392.9 spikes m^{-2} during the two seasons. In contrast, the Bo10 variety recorded the lowest rate, with 289.3 and 304.8 spikes m^{-2} during the two seasons. It is noteworthy that there were no significant differences between the Bo10 and Baghdad varieties in both seasons, indicating their similar performance in this trait (3).

On the other hand, no significant differences were observed between the interaction treatments of weed control methods and the studied varieties during both seasons, suggesting that the impact of weed removal or retention was similar across the different varieties without a significant interactive effect (25).

Number of grains (spike^{-2})

It is evident from Table 8 that weed removal had a positive effect on the number of grains per spike. The treatment where weeds were removed recorded the highest number of grains per spike, reaching (56.44 and 69.05) grains per spike during the two studied seasons (19). These values were significantly higher compared to the treatment where weeds were not removed, which recorded the lowest number of grains, amounting to (34.84 and 43.69) grains per spike in the respective seasons. This superiority is attributed to the reduced competition for nutrients, water and light upon weed removal (22), allowing the crop plants to maximize their utilization of environmental factors, achieve better growth and enhance productivity.

Table 6. Plant height (cm)

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	85.17	99.53	70.23	78.32	83.31	82.60	96.97	67.33	76.09	80.75
NW	95.71	101.20	78.69	79.35	88.74	93.48	99.01	78.13	76.78	86.85
FW	97.36	102.10	88.92	90.20	94.64	93.80	99.87	86.69	87.64	92.00
W	71.19	89.53	68.53	68.36	74.40	68.62	86.97	66.63	66.13	72.09
Mean	87.36	98.09	76.59	79.05	85.27	84.62	95.70	74.69	76.66	82.92
LSD ≤ 0.05	Weeds 4.499		Varieties 2.356		W.T. × V 5.617	Weeds 3.448		Varieties 2.489		W.T. × V 5.163

Table 7. Number of spikes (m^{-2})

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	285.0	336.0	378.3	391.3	347.7	299.0	351.3	393.3	406.3	362.5
NW	320.7	353.3	407.0	386.3	366.8	336.7	365.0	422.0	394.0	379.4
FW	331.3	369.3	470.0	432.3	400.8	348.0	388.0	451.7	440.7	407.1
W	220.3	292.3	237.0	305.0	263.7	235.3	307.3	254.3	330.7	281.9
Mean	289.3	337.8	373.1	378.8	344.7	304.8	352.9	380.3	392.9	357.7
LSD ≤ 0.05	Weeds 24.07		Varieties 28.52		W.T. × V n. s.	Weeds 20.99		Varieties 25.17		W.T. × V n. s.

Table 8. Number of grains (spike^{-1})

	First year					Second year				
	Bo_{22}	Bo_{10}	Bo_{22}	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	42.60	37.80	51.10	50.60	45.53	53.40	47.37	63.83	63.30	56.97
NW	50.53	45.07	53.23	55.97	51.20	63.30	56.33	66.73	70.00	64.09
FW	52.90	51.30	61.83	59.73	56.44	66.23	60.83	77.47	71.67	69.05
W	34.37	31.03	35.07	38.90	34.84	42.97	39.00	44.03	48.77	43.69
Mean	45.10	41.30	50.31	51.30	47.00	56.47	50.88	63.02	63.43	58.45
LSD ≤ 0.05	Weeds 3.518		Varieties 3.045		W.T. × V n. s.	Weeds 3.160		Varieties 3.080		W.T. × V n. s.

The Ibaa 99 cultivar demonstrated a marked superiority over the other cultivars, producing 51.30 and 63.43 grains per spike during the two growing seasons, respectively. This performance highlights the cultivar's favourable genetic characteristics, which likely contribute to its enhanced productivity. In contrast, the Buhuth 10 cultivar recorded the lowest grain count per spike, with averages of 41.30 and 50.88 across the two seasons. This reduced performance may be attributed to inherent genetic differences or its relatively lower adaptability to environmental conditions compared to Ibaa 99 (21-24).

Regarding the interaction between weed removal treatments and cultivars, the findings indicated no significant interaction effects in either season. This suggests that the influence of weed removal and cultivar type was independent, with no substantial impact of one factor on the response of the other.

Weight of 1000 grains (g)

Weight of 1000 grains (g) compared to all other treatments, with recorded values of (37.61 and 38.95) for the first and second seasons, respectively (Table 9). This superiority was statistically significant, as the weed-free treatment significantly outperformed the weed-infested treatment, which recorded the lowest rate for this trait, with values of (22.89 and 27.57) g in the first and second seasons, respectively as shown in Table 9. This reduction in weight is attributed to the competition exerted by weeds on plants, which reduces their ability to absorb nutrients and water, consequently leading to a decrease in grain weight. On the other hand, there were no significant differences between the treatments that included narrow-leaved weeds and those that included broad-leaved weeds during both seasons, indicating that the type of weeds did not have a substantial impact on this trait.

Table 9 also shows that the two varieties, Buhuth 10 and Buhuth 22, significantly outperformed the other two varieties in terms of the average weight of 1000 grains. In the first season, the varieties Buhuth 10 and Buhuth 22 recorded values of (34.78 and 34.75) g, while these values slightly increased in the second season to (35.52 and 35.81) g, reflecting a relatively stable performance (20). In contrast, the varieties "Baghdad" and "Ibaa 99" showed lower averages, recording (32.17 and 32.50) g in the first season and (33.18 and 32.849) g in the second season. This variation indicates genetic differences among the varieties in terms of efficiency in resource absorption and production of heavier grains.

Regarding the interaction between factors, the two-way interaction between the weed-free treatment and the variety Buhuth 22 had a positive and significant effect, recording the highest average weight of 1000 grains, with values of (6.261 and 6.862) g for the two seasons, respectively. This superiority reflects the ability of this variety to optimally benefit from ideal conditions in the absence of weed competition. In contrast, the interaction between the weed-infested treatment and the variety Buhuth 10 was the weakest, recording the lowest rate for this trait, with values of (1.657 and 1.824) g for the first and second seasons, demonstrating the negative impact of weeds on the growth and productivity of this specific variety.

On the other hand, there were no significant differences between the interactions of the weed-free treatment with the variety Buhuth 22and its interaction with the variety "Buhuth 10", indicating the similar performance of these two varieties under optimal conditions in the absence of weeds (26). This highlights the importance of selecting the appropriate variety and suitable environmental conditions to enhance grain productivity.

Grain yield (ton ha^{-1})

Table 10 illustrates that the weed-free treatment resulted in the highest average grain yield, reaching 5.762 and 6.331 tons ha^{-1} across the studied growing seasons. This yield advantage is attributed to the elimination of competition for essential growth resources-such as water, nutrients and sunlight-allowing the crop to grow more efficiently and maximize its productivity. Conversely, the weedy treatment led to a substantial decline in grain yield, with values of 2.471 and 2.509 tons ha^{-1}, underscoring the negative impact of weed competition on crop performance due to the constant struggle for vital environmental resources.

Table 10 also shows that the cultivar Buhuth 22 significantly outperformed the other cultivars in terms of grain yield, recording the highest averages of 5.087 and 5.523 tons ha^{-1}. This superior performance is likely attributed to its favorable genetic traits, which may include enhanced nutrient uptake efficiency and adaptability to varying environmental conditions, contributing to increased productivity.

In contrast, the Buhuth 10 cultivar produced the lowest yields 3.378 and 3.715 tons ha^{-1} possibly due to its limited adaptability or lower tolerance to environmental stress factors affecting crop growth and development.

For the Baghdad and Ibaa 99 cultivars, there were no significant differences in grain yield, indicating similar agronomic performance and comparable responses to environmental conditions during the study period.

Table 9. Weight of 1000 grains (g)

	First year					Second year				
	Bo$_{10}$	**Bo$_{22}$**	**Baghdad**	**EBAA**	**Mean**	**Bo$_{10}$**	**Bo$_{22}$**	**Baghdad**	**EBAA**	**Mean**
BW	33.39	36.60	33.12	32.32	33.86	33.98	37.83	33.49	32.66	34.49
NW	36.32	37.60	36.31	32.97	35.80	36.79	38.53	36.68	33.32	36.33
FW	37.34	39.45	36.34	37.29	37.61	38.14	40.56	39.44	37.67	38.95
W	32.07	25.37	22.89	27.40	26.93	33.17	26.30	23.12	27.69	27.57
Mean	34.78	34.75	32.17	32.50	33.55	35.52	35.81	33.18	32.84	34.34
LSD ≤ 0.05	Weeds 4.456		Varieties 1.763		W.T. × V 5.004	Weeds 3.300		Varieties 1.641		W. T. × V 4.024

Table 10. Yield (ton ha^{-1})

	First year					Second year				
	Bo$_{10}$	**Bo$_{22}$**	**Baghdad**	**EBAA**	**Mean**	**Bo$_{10}$**	**Bo$_{22}$**	**Baghdad**	**EBAA**	**Mean**
BW	2.607	5.053	4.298	4.049	4.002	2.867	5.523	4.728	4.453	4.393
NW	4.547	5.727	4.988	5.779	5.260	4.996	6.300	5.485	6.403	5.796
FW	4.703	6.261	5.797	6.285	5.762	5.174	6.862	6.377	6.911	6.331
W	1.657	3.305	2.621	2.302	2.471	1.824	3.407	2.295	2.510	2.509
Mean	3.378	5.087	4.426	4.604	4.374	3.715	5.523	4.721	5.069	4.757
LSD ≤ 0.05	Weeds 0.3363		Varieties 0.3295		W.T. × V 0.6306	Weeds 0.3345		Varieties 0.3126		W. T. × V 0.6041

Moreover, the interaction between weed control treatments and cultivars had a significant effect on grain yield, highlighting the importance of integrating crop and weed management practices. The combination of Buhuth 22 with the weed-free treatment recorded the highest grain yield-6.261 and 6.862 tons ha^{-1} demonstrating the substantial benefit of weed-free conditions on this cultivar's productivity (26). However, no significant differences were observed between this combination and the Ibaa 99-weed-free interaction in either season, suggesting both cultivars respond well to optimal.

Biological yield (ton ha^{-1})

Table 11 presents the biological yield results, revealing that the weed-free treatment consistently produced the highest average yields 16.09 and 20.24 tons ha^{-1} across the two growing seasons. This superior performance is largely attributed to the elimination of competition between the crop and weeds, allowing the plants to fully utilize essential resources such as water, nutrients and sunlight. In contrast, the treatment that allowed weed growth resulted in the lowest biological yields, recording 9.84 and 12.35 tons ha^{-1}, respectively. These findings underscore the negative impact of weed competition, which hinders the crop's ability to access critical growth inputs, thereby reducing overall productivity (27). The weed-free treatment consistently outperformed all others across both seasons, further emphasizing the detrimental effects of weed interference on yield.

Regarding varietal performance, the Baghdad variety exhibited a statistically significant advantage over the other cultivars, achieving the highest mean biological yields of 14.98 and 18.68 tons.ha^{-1}. This superior outcome is likely due to its favorable genetic characteristics, which enhance resource-use efficiency under the given environmental conditions. On the other hand, the Buhuth 10 variety recorded the lowest yields (10.25 and 12.89 tons ha^{-1}), suggesting a comparatively lower adaptive capacity. However, no significant differences were found among Buhuth 22, Baghdad and Ibaa 99, indicating a generally similar level of production efficiency among these varieties across both seasons.

Furthermore, the interaction between weed management strategies and varietal differences had a statistically significant effect on biological yield. The highest yields 17.57 and 22.13 tons ha^{-1} were achieved by the combination of the weed-free treatment and the Baghdad variety. This outstanding result reflects the synergistic benefits of effective weed control combined with the high-performing traits of the Baghdad cultivar. Nevertheless, no significant differences were observed between this combination and those involving the weed-free treatment with Buhuth 22 and Ibaa 99, indicating that these varieties also possess strong production potential when cultivated under optimal, weed-free conditions.

Spike length (cm)

Table 12 indicates that the treatment without weeds recorded the highest average spike length during both seasons, with an average of (12.586 and 14.992 cm), respectively (12). This superiority is attributed to the absence of competition from weeds for essential resources such as water, light and nutrients, allowing the plants to grow better and achieve an increase in spike length. In contrast, the treatment exposed to weeds recorded the lowest average spike length, measuring (10.305 and 12.193 cm) in the first and second seasons, respectively. This reduction is due to the negative impact of weeds, which compete with cultivated plants for resources, leading to weaker growth and shorter spikes.

When comparing cultivars, the data show that the cultivar Buhuth 10 significantly outperformed the other studied cultivars, with an average spike length of (12.145 and 14.546 cm) during both seasons. This superiority is attributed to the genetic traits of this cultivar, which enable it to achieve better growth under the studied environmental conditions. Conversely, the cultivar "Baghdad" recorded the lowest average spike length, measuring (10.592 and 12.765 cm) during both seasons, which may be due to its lower response to environmental factors or its limited ability to optimally utilize available resources. Notably, no significant differences were recorded between the cultivar Buhuth 10 and the cultivars Buhuth 22and Ebaa 99, indicating that these cultivars exhibit a similar response in terms of spike length under the studied conditions.

Regarding the interaction effect between weed treatment and the studied cultivars, this interaction had a significant impact on spike length during the second season. The results showed that the interaction between the weed-free treatment and the cultivar Buhuth 10 resulted in the highest spike length, reaching (15.770 cm) (17, 22, 25). This is due to the combination of the superior cultivar and the care of its plants in a competition-free environment, allowing for optimal growth. On the other hand, the lowest spike length (11.3 cm) was recorded in the interaction between the weedy treatment and the cultivar "Buhuth 22", reflecting the negative impact of weeds on the growth of this specific cultivar, as it faced intense competition that significantly affected its growth (27).

Table 11. Biological yield (ton ha^{-1})

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	9.51	14.06	14.76	14.23	13.14	12.00	17.80	18.62	17.95	16.59
NW	13.33	14.73	16.01	16.12	15.05	16.80	18.91	20.17	20.32	19.05
FW	12.56	16.77	17.57	17.38	16.07	15.74	21.17	22.13	21.92	20.24
W	5.59	11.60	11.58	10.58	9.84	7.03	15.46	13.58	13.32	12.35
Mean	10.25	14.29	14.98	14.57	13.52	12.89	18.33	18.62	18.37	17.06
LSD ≤ 0.05	Weeds 1.041		Varieties 0.659		W.T. x V 1.436	Weeds 0.812		Varieties 0.671		W. T. x V 1.336

Table 12. Spike length (cm)

	First year					Second year				
	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean	Bo_{10}	Bo_{22}	Baghdad	EBAA	Mean
BW	12.123	12.047	10.597	11.943	11.677	14.513	14.483	12.907	14.300	14.051
NW	13.120	12.467	10.667	12.587	12.210	15.700	14.940	12.833	15.200	14.668
FW	13.143	13.090	11.567	12.543	12.586	15.770	15.040	13.880	15.000	14.922
W	10.193	10.030	9.537	11.460	10.305	12.200	11.300	11.440	13.833	12.193
Mean	12.145	11.908	10.592	12.133	11.695	14.546	13.941	12.765	14.583	13.959
LSD ≤ 0.05	Weeds 0.7439		Varieties 0.5089		W.T. × V NS	Weeds 0.5763		Varieties 0.5489		W.T. × V 1.0567

Conclusion

Complete weed removal significantly enhanced all studied traits, including plant height, number of spikes and 1000-grain weight, resulting in a substantial increase in wheat yield. The cultivar Buhuth 22 consistently outperformed the other cultivars, recording the highest grain yield and demonstrating superior competitive ability against weeds. Rapid-growing and dense cultivars exhibited greater resistance to weed interference, making them more suitable for sustainable wheat production under weed-infested conditions.

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Authors' contributions

AJA contributed to the proposal of the study, specimen collection and data analysis. NAM wrote and revised the manuscript and supervised the study. KAS and AFA conducted the experimentation, data collection and laboratory work. AHA carried out experimentation and data collection. IEE contributed by making edits to the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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