RESPONSE OF YIELD INDICATORS OF TWO WHEAT CULTIVARS TO WEED CONTROL TREATMENTS AND INTER-ROW SPACING

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Abstract

The study was conducted during the winter season of 2025–2026 in Jadidat Al-Shat District, Diyala Province, Iraq, to evaluate the effects of wheat cultivars and row spacing on weed dynamics, plant growth, and yield under different weed-control strategies. The experiment was arranged as a split-split plot within a randomized complete block design (RCBD), with three replications. Treatments included Boxer Cold applied pre-emergence, Timeline applied post-emergence, weed-free, and weedy checks, using the wheat cultivars Buhuth 22 and Sonbolatin at row spacing's of 10, 15, and 20 cm. Boxer Cold produced the highest values for tiller number (390.22 tillers 0.25 m^{-2}), plant height (75.51 cm), and flag leaf area (24.46 cm^2). Sonbolatin produced the highest tiller number, whereas Buhuth 22 recorded the greatest plant height and flag leaf area. The 20-cm spacing produced the highest tiller number and flag leaf area, while the narrowest spacing (10 cm) increased plant height. The interaction Boxer Cold × Sonbolatin × 20 cm produced the highest tiller number (515 tillers 0.25 m^{-2}), whereas Boxer Cold × Buhuth 22 × 10 cm produced the greatest plant height (105 cm) and flag leaf area (35.00 cm^2). For yield components, Boxer Cold resulted in the highest spike number (324.44 spikes 0.25 m^{-2}), grains $spike^{-1}$ (75.63), 1000-grain weight (41.41 g), grain yield (4.76 $t.ha^{-1}$), and biological yield (14.69 $t.ha^{-1}$). The 15-cm spacing produced the highest spike number, grains $spike^{-1}$, and grain yield. The three-way interaction Boxer Cold × Sonbolatin × 15 cm achieved the highest spike number (455), $grains.spike^{-1}$ (84.90), and grain yield (6.26 $t.ha^{-1}$). Overall, integrating Boxer Cold application with suitable cultivar and row spacing effectively reduced weed competition and enhanced wheat growth and yield.

Keywords: Herbicides, weeds, wheat cultivars, inter-row spacing, plant yield.

INTRODUCTION

The importance of wheat for human life can hardly be overestimated. Wheat is regarded as a staple food for over 35% of the population of the Earth. The challenge of maintaining an equilibrium between the amount of the crops produced and the amount required can be solved thanks to effective management of this crop and efficient agronomic practices that allow getting a healthy crop stand. Wheat is the leading cereal crop around the world, which indicates that efforts to increase its production are necessary. According to data, wheat production in Iraq was equal to 4,379 thousand tons during the winter season of 2025, which is 16.3% less than in 2024 when the amount of production was equal to 5,234 thousand tons. The area of cultivation in 2025 was equal to 7,050 thousand dunums, which is 13.8% less than the area cultivated in 2024 **[1].** The decrease in the levels of the domestic production is related to a wide range of factors, but poor crop management can be named as the main factor.

Various types of weed are common in the wheat fields of Iraq causing negative effects on wheat production. If weeds left to thrive unabated, wheat crop yield could suffer

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serious losses up to 59.4% of the field yield **[2, 3]**. Since weeds normally are good competitors against wheat plants in terms of competition for water, nutrient and light, especially in the early stages of crop development, wheat plants would suffer as a consequence impacting negatively on production **[4]**.

Weeds and their density accompany difficulties that crops have. Weeds with high density and long competition with wheat deliver significant yield losses **[5]**. Weed competition for wheat results in yield losses much higher than that of some pests and disease attack **[6]**. Weed control plays a central role in providing sustainable wheat production. Herbicides are the key tool in modern agriculture due to their effectiveness against weeds and labor-saving capability **[7]**. Choosing proper herbicides and studying their influence on yield of wheat are critical for maximizing productivity keeping environment safe **[8]**.

Chemical weed control is seen as one of the new technologies in agriculture, and using herbicides can lead to increased harvests **[9]**. In order to limit competition between weeds and crops, there should be a constant search for new herbicides that are better than already existing ones. This is essential due to the fact that repeated use of the same herbicide for years can lead to the selection of those weeds that genome makes them resistant to herbicides and able to reproduce and transfer this property to their descendants **[10]**.

Weed control is important for crop yield and productivity improvements on farms. The use of herbicides will still be part of weed control programs for wheat, since applying pre- and post-emergence herbicides can minimize the harmful effects associated with weeds. However, the use of herbicides may have environmental implications and is not always practical or affordable for every farmer. Thus, Integrated Weed Management (IWM) is a more viable and economically sound option in this regard. IWM involves the application of knowledge and research-based methods of weed-management systems based on data about environmental conditions, weed biology, environmental ecosystems, and available means of weed control **[11]**. Using effective and varied weed-control methods allows farmers to manage weeds more effectively and limits the chances for the adaptation of weeds to one of the control methods. The efficiency of IWM depends on the use of all possible methods that can be used locally **[10]**.

MATERIALS AND METHODS

A field experiment was conducted in Diyala Governorate, Iraq, during the 2025–2026 winter growing season to investigate the effects of pre-emergence and post-emergence herbicides, as well as manual weed removal, on weed competitiveness, growth, and yield traits of two wheat cultivars under different inter-row spacings.

The weed-control treatments included the pre-emergence herbicide Boxer Cold, which contains 800 $g.L^{-1}$ prosulfocarb and 130 $g.L^{-1}$ S-metolachlor as active ingredients, and the post-emergence herbicide Timeline, which contains 30 $g.L^{-1}$ pinoxaden, 30 $g.L^{-1}$ clodinafop-propargyl, and 7.5 $g.L^{-1}$ florasulam. In addition, weed-free treatment, where weeds are removed manually throughout the growing season, and unweeded (weedy) control are included in order to assess competitive effects of weeds on wheat plants.

Two cultivars of wheat, namely Buhuth 22 and Sanblatain, were planted on 25th November 2025. The planting was done in rows, with inter-row spacing of 10, 15, and 20 cm, using a seed rate of 140 $kg.ha^{-1}$. The Boxer Cold herbicide was applied 48 hours

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after the germination irrigation, when the soil was at field capacity, and 27 days after the germination irrigation, the Timeline herbicide was applied when the weeds had grown to 3–5 leaves. The application of both these herbicides was done using a battery-powered knapsack sprayer. Manually removing the weeds from the rest of the experimental plots was done during the whole growth season.

The soil type of the experimental area was delineated as sandy clay loam, comprising 48% sand, 16% clay, and 36% silt.

Collected data from all experimental plots underwent statistical analysis to determine the efficiency of the herbicide treatment and impact on growth variables such as the number of tillers, height of plants, area of flag leaf, and yield variables such as the number of spikes, number of grains in each spike, weight of 1000 grains, grain yield, biological yield, and weed control efficacy .

Growth and yield measurement were obtained through the 0.50 m × 0.50 m quadrat (0.25 m²) randomly laid down for each experimental treatment.

Table 1. Information on the herbicides used in the experiment.

No.	Herbicide	Active ingredient(s)	Mode of action	Application rate
1	**Boxer Cold**	**Prosulfocarb + S-metolachlor**	**Inhibition of very-long-chain fatty acid (VLCFA) synthesis**	**2 L.ha^{-1} in 400 L water**
2	**Timeline**	**Pinoxaden + Clodinafop-propargyl + Florasulam**	**Pinoxaden: inhibition of acetyl-CoA carboxylase (ACCase). Florasulam: inhibition of acetolactate synthase (ALS)**	**1.25 L.ha^{-1} in 400 L water**

Traits Evaluated

-Wheat Growth Traits

Plant Height (cm): The height of plants was determined as an average of ten measurements taken within each experimental unit, from the ground level to the base of the inflorescence stalk of the plant **[12]**.

Number of Tillers (tillers 0.25 m^{-2}): At the point where tillering had been completed and stem elongation was beginning, the number of tillers in an area of 0.25 m² was measured in each of the experimental units **[13]**.

Flag Leaf Area (cm²): Flag leaf area was calculated from the mean of ten flag leaves from the main stems of each experimental unit at 100% flowering, utilizing the following equation **[14]**:

Flag leaf area (cm²) = Flag leaf length × Maximum flag leaf width × 0.95

-Yield and Yield Components

Number of Spikes (spikes 0.25 m^{-2}): The number of spikes was estimated by counting all spikes of the harvested plants within an area of 0.25 m² from each experimental unit.

Number of Grains per Spike: From each experimental unit, 10 spikes were picked up randomly and threshed manually. The number of grains was counted, from which the average number of grains per spike was calculated by dividing by 10 **[15]**.

1000-Grain Weight (g): A random selection of one thousand grains from every experimental unit was made and weighed using a precision balance. The measurement was performed three times for each sample, and the average of all results was calculated **[15]**.

Grain Yield (t.ha^{-1}): After harvesting plants from a plot of land of 0.25 m² per experiment, the straw was threshed from the grains. The weight of thegrains was determined including that obtained by

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obtaining the grain from ten spikes used in determining the number of grains per spike. The grain weight was converted to $t.ha^{-1}$ **[16]**.

Biological Yield ($t.ha^{-1}$): The biological yield in each experiment was measured in terms of dry weight of the harvested plant material **[17]**.

Each sample was weighed using a precise balance with its values being converted into $t.ha^{-1}$.

-Weed Traits

Herbicide Efficiency Index (HEI)

The Herbicide Effectiveness Index (HEI) has been used to determine the effectiveness of herbicides in controlling weeds without negatively affecting crop productivity **[18]**. This index evaluates the ability of a herbicide to satisfy both objectives: proper weed management and crop production maintaining or improving the quality of crop productivity without inflicting physical damage or hindering growth. The higher HEI values indicate the higher efficiency of the herbicide in controlling weed biomass, as well as crop production, which shows the efficiency level of the treatment. In contrast, low HEI values indicate low herbicide efficiency in controlling weeds.

The variables used in calculating the index were defined as follows:

$$HEI = \frac{\frac{YT - YC}{YC}}{\frac{DWT}{DWC}}$$

- **YT:** Yield of the herbicide-treated plot.
- **YC:** Yield of the unweeded control plot.
- **DWT:** Weed dry weight in the herbicide-treated plot.
- **DWC:** Weed dry weight in the unweeded control plot.

Statistical Analysis

The data are analyzed statically through analysis of variance (ANOVA) or analysis of covariance (ANCOVA) wherever necessary through GenStat software. The treatment mean comparisons are done applying least significant difference (LSD) test with a significant level of 5% ($P \leq 0.05$) as determined by the general analysis of variance the diameter: Stem Circumference (cm) = Diameter x Constant Ratio

RESULTS AND DISCUSSION

According to the findings from the statistical assessment presented in Table 2, it was found that all of the weed-prevention techniques utilized impacted every one of the parameters being studied. In terms of the average number of tillers it had, the weed-free control had the highest value, with 419.33 tillers in 0.25 m^2, while the weed-infested control had the lowest number of 348.50 tillers in 0.25 m^2. The weed-repellent technique indicated that the height of the plants involved in this experiment was at its maximum of 83.95 cm, whereas the level of the plant height recorded by the weedy controls was the lowest at 60.01 cm. In the same way, the highest amount of flag leaf area was 27.88 cm^2 for the weed-free control and its lowest amount was 18.01 cm^2 for the weedy controls. This is probably because weeds are properly removed, leading to their reduced dry weight as well as their internal competition between the wheat plants and its seedlings for important sources of water, light, and nutrients. The lower competition enables the photosynthesis process to improve efficiency and production **[19, 20]**.

In terms of tillers, the Sanblatain variety yielded the most number since it generated the highest average of 445.67 tillers per 0.25 square meters, while Buhuth 22 produced the least average of 317.78 tillers per 0.25 square meters. Buhuth 22 yielded the highest average plant height as 87.53 cm, while Sanblatain resulted in the shortest plant height with a mean height of 56.38 cm. At the same time, Buhuth 22 produced the highest flag leaf area with a mean of 28.53

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square cm, while Sanblatain produced the thinest flag leaf area of 17.10 square cm. The differences can be explained by the variations in genetics among different wheat cultivars and traits related to their growing abilities **[21]**.

The spacing of 20 cm between rows showed the maximum total number of tillers (419.17 tillers/0.25 m²) as compared with the spacing of 10 cm that exhibited the least total number of tillers (333.88 tillers/0.25 m²). On the contrary, spacing of 10 cm registered the maximum average plant height (81.30 cm) while the 20 cm spacing showed the minimum average plant height (62.77 cm). The spacing of 20 cm displayed the maximum average leaf area of flag leaf (26.92 cm²) compared to the least area (18.69 cm²) obtained for spacing of 10 cm. The arrangement of crops may lead to restricting the light reaching the weeds and facilitate their control, thus providing the crop a competitive advantage without any extra cost or environmental impairment **[22]**.

Table 2. Effect of weed-control treatments, wheat cultivars, and inter-row spacing on wheat growth indicators

Treatments	Number of Tillers (tillers 0.25 m^{-2})	Plant Height (cm)	Flag Leaf Area (cm^2)
Weed-Control Treatments			
Weedy	**348.50**	**60.01**	**18.01**
Weed-free	**419.33**	**83.95**	**27.88**
Boxer Cold	**390.22**	**75.51**	**24.46**
Time Line	**368.83**	**68.36**	**20.91**
Wheat Cultivars			
Buhuth 22	**317.78**	**87.53**	**28.53**
Sanblatain	**445.67**	**56.38**	**17.10**
Inter-Row Spacing (cm)			
10	**333.88**	**81.30**	**18.69**
15	**392.12**	**71.80**	**22.84**
20	**419.17**	**62.77**	**26.92**
$LSD_{0.05}$			
H	**0.96**	**0.59**	**0.17**
V	**0.64**	**0.32**	**0.16**
S	**0.69**	**0.27**	**0.23**

Note: H = Weed-control treatments; V = Wheat cultivars; S = Inter-row spacing; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level.

Table 3 shows that the interaction between the treatments for weed control and the wheat varieties affected growth parameters considerably. The best results for tillering were obtained within the weed-free × Sanblatain combination, which achieved 500 tillers per 0.25 m², which is significantly higher than the weedy × Buhuth 22, which had the lowest value of 289.33 tillers per 0.25 m². In terms of height also, the weed-free × Buhuth 22 combination showed the best result (101.81 cm), while the weedy × Sanblatain combination had the lowest plant height (46.78 cm). Likewise, the flag leaf area was also reported to be largest in weed-free × Buhuth 22 combination (35.00 cm²) and smallest in the weedy × Sanblatain (13.57

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cm²) combination. These results conform to the findings of **[23]** and **[24]**, who also found a significant difference between varieties of wheat and weed-control treatments that was due to genetic characteristics and differences in reactions of those two varieties.

Table 3. Effect of weed-control treatments and wheat cultivars on wheat growth indicators

Weed-Control Treatments	Wheat Cultivars	Number of Tillers (tillers 0.25 m^{-2})	Plant Height (cm)	Flag Leaf Area (cm^2)
Weedy	**Buhuth 22**	**289.33**	**73.23**	**22.44**
	Sanblatain	**407.67**	**46.78**	**13.57**
Weed-free	**Buhuth 22**	**338.67**	**101.81**	**35.00**
	Sanblatain	**500.00**	**66.10**	**20.77**
Boxer Cold	**Buhuth 22**	**325.44**	**92.30**	**30.60**
	Sanblatain	**455.00**	**58.72**	**18.33**
Time Line	**Buhuth 22**	**317.67**	**82.80**	**26.10**
	Sanblatain	**420.00**	**53.93**	**15.72**
$LSD_{0.05}$ (H × V)		**1.19**	**0.68**	**0.26**

Note: H = Weed-control treatments; V = Wheat cultivars; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level

The findings shown in Table 4 suggest that there was a remarkable impact of the interaction of weed control methods and inter-row distance on the growth features studied in the current experiment. The combination of weed-free × 20 cm recorded the highest average value of tilleries (448.00 tillers per 0.25 m²) while the lowest average value of tilleries (324.00 tillers per 0.25 m²) was observed in the case of the combination of weedy × 10 cm. In terms of height, the weed-free × 10 cm combination recorded the highest mean value of 95.00 cm whereas weeded × 20 cm combination recorded the lowest mean height of plants (52.80 cm). This can be justified by the unlimited competitive pressure on crop plants to absorb light and other growth resources **[25]**. The weed-free × 20 cm combination also showed the highest mean flag leaf area (33.00 cm²) compared to the mean flag leaf area of the combination weedy × 10 cm which was the lowest overall (14.56 cm²).

Table 4. Effect of Weed-Control Treatments and Inter-Row Spacing on Wheat Growth Indicators

Weed-Control Treatments	Inter-Row Spacing (cm)	Number of Tillers (tillers 0.25 m^{-2})	Plant Height (cm)	Flag Leaf Area (cm^2)
Weedy	**10**	**324.00**	**67.68**	**14.56**
	15	**355.00**	**59.55**	**18.35**
	20	**366.50**	**52.80**	**21.11**
Weed-free	**10**	**344.00**	**95.00**	**23.00**
	15	**430.00**	**84.06**	**27.66**
	20	**448.00**	**72.80**	**33.00**

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Boxer Cold	**10**	**335.00**	**85.85**	**20.10**
	15	**403.00**	**75.50**	**24.30**
	20	**430.00**	**65.18**	**29.00**
Time Line	**10**	**332.50**	**76.70**	**17.10**
	15	**378.00**	**68.10**	**21.05**
	20	**395.50**	**60.30**	**24.58**
$LSD_{0.05}$ (H × S)		**1.38**	**0.69**	**0.41**

Note: H = Weed-control treatments; S = Inter-row spacing; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level.

The findings displayed in Table 5 revealed that the interaction between wheat varieties and the distance between the rows had a remarkable influence on the investigated growth characteristics. The combination of Sanblatain and 20 cm distance showed the highest average number of tillers (498.75 tillers for 0.25 m²) as opposed to Buhuth 22 combination with the lowest average number of tillers (283.25 tillers for 0.25 m²). Regarding the highest average plant height, the Buhuth 22 × 10 cm combination displayed the maximum value (100.00 cm), while Sanblatain × 20 cm combination recorded the minimum average plant height (50.49 cm). As for the flag leaf area, Buhuth 22 × 20 cm combination displayed the highest average value (32.66 cm²) in comparison with the Sanblatain × 10 cm combination with the lowest average flag leaf area (13.11 cm²).

Table 5. Effect of Wheat Cultivars and Inter-Row Spacing on Wheat Growth Indicators

Wheat Cultivars	Inter-Row Spacing (cm)	Number of Tillers (tillers 0.25 m^{-2})	Plant Height (cm)	Flag Leaf Area (cm^2)
Buhuth 22	**10**	**283.25**	**100.00**	**24.26**
	15	**330.50**	**87.55**	**28.67**
	20	**339.58**	**75.05**	**32.66**
Sanblatain	**10**	**384.50**	**62.61**	**13.11**
	15	**453.75**	**56.05**	**17.00**
	20	**498.75**	**50.49**	**21.18**
$LSD_{0.05}$ (V × S)		**0.97**	**0.43**	**0.30**

Note: V = Wheat cultivar; S = Inter-row spacing; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level

The findings indicated that three-way interactions that resulted from treatments of wheat cultivars, inter-row spacing, and weed control have drastic effect on growth attributes. The treatment combinations of weed-free × Sanblatain × 20 cm had the maximum mean number of tillers (600.00 tillers/0.25 m²), while the weedy × Buhuth 22 × 10 cm treatment had the least mean number of tillers (275.00/0.25 m²). As for plant height, the treatment combination of weed-free × Buhuth 22 × 10 cm yielded the

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maximum mean value (115 cm), while weedy × Sanblatain × 20 cm resulted in the least plant height (44 cm) showing meaning for the specified interaction effects on plant height. In terms of flag leaf area, the best treatment combination was weed-free × Buhuth 22 × 20 cm (40 cm^2) and, on the contrary, the worst treatment combination was weedy × Sanblatain × 10 cm (10.46).

Effective weed management is very important in order to control competition between crops and weeds and prevent the spread of invasive weeds. Different approaches can be used for effective weed management, such as mechanical weeding, the use of cover crops, proper spacing between crops, and the application of specific herbicides **[26].**

Table 6. Effect of the three-way interaction among weed-control treatments, wheat cultivars, and inter-row spacing on wheat growth indicators

Weed-Control Treatments	Wheat Cultivars	Inter-Row Spacing (cm)	Number of Tillers (tillers 0.25 m^{-2})	Plant Height (cm)	Flag Leaf Area (cm^2)
Weedy	**Buhuth 22**	**10**	**275.00**	**85.00**	**18.66**
		15	**290.00**	**73.10**	**23.00**
		20	**303.00**	**61.60**	**25.66**
	Sanblatain	**10**	**373.00**	**50.36**	**10.46**
		15	**420.00**	**46.00**	**13.70**
		20	**430.00**	**44.00**	**16.56**
Weed-free	**Buhuth 22**	**10**	**288.00**	**115.00**	**30.00**
		15	**360.00**	**102.03**	**35.00**
		20	**368.00**	**88.40**	**40.00**
	Sanblatain	**10**	**400.00**	**75.00**	**16.00**
		15	**500.00**	**66.10**	**20.33**
		20	**600.00**	**57.20**	**26.00**
Boxer Cold	**Buhuth 22**	**10**	**285.00**	**105.00**	**26.20**
		15	**345.00**	**92.30**	**30.60**
		20	**346.00**	**79.60**	**35.00**
	Sanblatain	**10**	**385.00**	**66.70**	**14.00**
		15	**465.00**	**58.70**	**18.00**
		20	**515.00**	**50.76**	**23.00**
Time Line	**Buhuth 22**	**10**	**285.00**	**95.00**	**22.20**
		15	**327.00**	**82.80**	**26.10**
		20	**341.00**	**70.60**	**30.00**
	Sanblatain	**10**	**380.00**	**58.40**	**12.00**
		15	**430.00**	**53.40**	**16.00**
		20	**450.00**	**50.00**	**19.16**
$LSD_{0.05}$ (H × V × S)			**1.93**	**0.90**	**0.59**

Note: **H = Weed-control treatments; V = Wheat cultivars; S = Inter-row spacing; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level**

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According to the statistical analysis of the yield traits outlined in Table 7, the Boxer Cold treatment had the best performance in the majority of the yield trait evaluations. The mean number of spikes in this treatment was the highest at 324.44 spikes per 0.25m², leaving the weedy control in the last place at 238.39 spikes per 0.25m². The Boxer Cold treatment recorded the second highest mean number of grains per spike (75.63 grains), whereas the weedy control had the number of spikes of only 51.93 grains. The biggest difference was found in the mean weight of 1000 grains, Boxer Cold at 41.41 g compared to the weedy control, only 33.17 g. Finally, the lowest grain yield was found in the weedy control (3.10 $t.ha^{-1}$) compared to the Boxer Cold treatment (4.76 $t.ha^{-1}$). In terms of biological yield, the highest value (15.86 $t.ha^{-1}$) was measured in the weed-free treatment as opposed to the weedy control, which recorded the lowest measure (12.35 $t.ha^{-1}$). The obtained results should be explained by the proper weed management due to which the plants experienced lower competition from weeds **[27].**

The Sanblatain cultivar outperformed others in terms of number of spikes, reaching a highest value of spikes mean (356.47) in comparison to Buhuth 22, which recorded the lowest mean value (249.11). Moreover, the Sanblatain cultivar had the highest grains per spike value (74.57) compared with Buhuth 22, which reached 58.79, and the highest mean weight of 1000 grains (44.00 g) compared to Buhuth 22, which had a lower weight of 34.45 g. The same pattern repeats when it comes to grain yield, with Sanblatain with the highest value (4.69 $t.ha^{-1}$) and Buhuth 22 with the lowest grain yield value (3.83 $t.ha^{-1}$). The sole distinguishing feature of Buhuth 22 was the biological yield, which has reached the top of 14.46 t ha^{-1} against 13.18 of Sanblatain. This variation can be understood only as an effect of variations in growth characteristics between the varieties, which explains the much more effective ability of competitive abilities of the branched cultivar and its ability to inhibit the development of weeds **[28].**

In terms of inter-row spacing, the 15 cm distance had the highest average of total spikes (356.17 spikes) as opposed to the 20 cm distance which had the lowest average of total spikes (250.00 spikes). The 15 cm distance also had the highest average yield of grains per spike (70.39 grains) when compared with the 20 cm distance (63.11 grains). On the other hand, the 20 cm distance had the highest average weight of 1000 grains (41.43 g), while the 10 cm spacing produced the least average weight of 1000 grains (37.00 g). Also, 15 cm spacing provided the highest average grain yield (4.81 $t.ha^{-1}$) in comparison with the 20 cm spacing (3.85 $t.ha^{-1}$). Consequentially, the 10 cm distance produced the highest average biological yield (14.55 $t.ha^{-1}$) as opposed to the lowest average biological yield of 12.95 $t.ha^{-1}$ obtained from the 20 cm inter-row spacing.

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Table 7. Effect of weed-control treatments, wheat cultivars, and inter-row spacing on yield indicators

Treatment / Factor	Number of Spikes (spikes 0.25 m^{-2})	Number of Grains per Spike	1000-Grain Weight (g)	Grain Yield (t ha^{-1})	Biological Yield (t ha^{-1})
Weedy	**238.39**	**51.93**	**33.17**	**3.10**	**12.35**
Weed-free	**384.78**	**84.11**	**45.33**	**5.88**	**15.86**
Boxer Cold	**324.44**	**75.63**	**41.41**	**4.76**	**14.69**
Time Line	**299.56**	**55.05**	**36.44**	**3.30**	**12.36**
Buhuth 22	**249.11**	**58.79**	**34.45**	**3.83**	**14.46**
Sanblatain	**356.47**	**74.57**	**44.00**	**4.69**	**13.18**
10 cm	**302.21**	**66.55**	**37.00**	**4.11**	**14.55**
15 cm	**356.17**	**70.39**	**39.25**	**4.81**	**13.95**
20 cm	**250.00**	**63.11**	**41.43**	**3.85**	**12.95**
$LSD_{0.05}$ (H)	**0.41**	**0.29**	**0.09**	**0.19**	**0.09**
$LSD_{0.05}$ (V)	**0.56**	**0.13**	**0.064**	**0.131**	**0.00064**
$LSD_{0.05}$ (S)	**0.60**	**0.16**	**0.069**	**0.137**	**0.00069**

Note: H = Weed-control treatments; V = Wheat cultivars; S = Inter-row spacing; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level

The findings shown in Table 8 show that the combination of wheat types and methods for weed control has greatly impacted the achievements in wheat yield. The Boxer Cold × Sanblatain method obtained the largest number of spikes (370.89 spikes per 0.25 m^2) while the lowest number of spikes was observed in the weedy × Buhuth 22 combination (163.56 spikes per 0.25 m^2). The method of Boxer Cold × Sanblatain also obtained a high number of average grains per spike (82.13 grains) while the minimum number of grains was recorded in weedy × Buhuth 22 (41.93 grains). The maximum number of avg 1000-grain weight was reported by the Boxer Cold × Sanblatain combination (47.03 g) while the lowest result (30.33 g) was obtained from the weedy × Buhuth 22 combination.

With reference to grain yield, the combination of Boxer Cold and Sanblatain showed the highest mean yield, corresponding to 5.23 $t.h^{-1}$, while weedy combinations and Buhuth 22 demonstrated the lowest yield of 2.96 $t.h^{-1}$. However, as for biological yield, the combination of weed-free and Buhuth 22 produced the highest biological yield of 16.80 $t.h^{-1}$, while weedy and Sanblatain and Time Line and Sanblatain combinations demonstrated the lowest biological yield of 11.93 $t.h^{-1}$.

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Table 8. Effect of Weed-Control Treatments and Wheat Cultivars on Wheat Yield Indicators

Weed-Control Treatment	Wheat Cultivar	Number of Spikes (spikes 0.25 m^{-2})	Number of Grains per Spike	1000-Grain Weight (g)	Grain Yield ($t.ha^{-1}$)	Biological Yield ($t.ha^{-1}$)
Weedy	Buhuth 22	163.56	41.93	30.33	2.96	12.78
	Sanblatain	313.22	61.93	37.10	3.23	11.93
Weed-free	Buhuth 22	297.56	76.06	38.66	4.90	16.80
	Sanblatain	400.00	92.16	52.00	6.86	14.93
Boxer Cold	Buhuth 22	278.00	69.14	35.80	4.29	15.46
	Sanblatain	370.89	82.13	47.03	5.23	13.93
Time Line	Buhuth 22	257.33	48.03	33.00	3.16	12.80
	Sanblatain	341.78	62.06	39.88	3.43	11.93
$LSD_{0.05}$ (H × V)		0.84	0.31	0.11	0.24	0.09

Note: H = Weed-control treatments; V = Wheat cultivars; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level.

The findings shown in Table 9 revealed that the combination of weed control methods and inter-row spacing had a significant impact on the yield characteristics studied. In terms of the average number of spikes, the Boxer Cold × 15 cm combination achieved the maximum average number of spikes, which equaled 379.50 spikes per 0.25 m^2, in contrast to the weedy × 20 cm combination that achieved the minimum number of spikes (197.50 spikes per 0.25 m^2). The Boxer Cold × 15 cm combination also obtained the maximum average number of grains in a spike with a total of 80.96 grains, unlike the weedy × 20 cm treatment, which showed the minimum average (50.00 grains).

For the 1000-grain weight parameter, the highest mean value (48.00 g) was obtained through the weed-free × 20 cm combination whereas the lowest value (32.10 g) was obtained through the weedy × 10 cm combination. The highest grain yield value (5.60 $t.ha^{-1}$) was obtained from the Boxer Cold × 15 cm combination, while the lowest value (2.80 $t\ ha^{-1}$) was recorded for the weedy × 20 cm. For biological yield, the highest mean value (16.60 $t.ha^{-1}$) was obtained for the weed-free × 10 cm combination, while the lowest biological yield (11.50 $t.ha^{-1}$) was recorded for the weedy × 20 cm combination.

Inter-row spacing impacts weed growth and competition, as well as the density and productivity of weeds during different periods of crop-weed competition. Adequate row spacing may also affect the availability of resources and crop efficiency by changing the nature of the competition between weeds and wheat plants **[29].**

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Table 9. Effect of Weed-Control Treatments and Inter-Row Spacing on Wheat Yield Indicators

Weed-Control Treatment	Inter-Row Spacing (cm)	Number of Spikes (spikes 0.25 m^{-2})	Number of Grains per Spike	1000-Grain Weight (g)	Grain Yield (t ha^{-1})	Biological Yield (t ha^{-1})
Weedy	**10**	**229.83**	**51.75**	**32.10**	**3.10**	**13.10**
	15	**287.83**	**54.05**	**33.50**	**3.40**	**12.47**
	20	**197.50**	**50.00**	**35.55**	**2.80**	**11.50**
Weed-free	**10**	**345.00**	**83.30**	**42.50**	**5.80**	**16.60**
	15	**410.17**	**89.45**	**45.50**	**6.65**	**16.00**
	20	**291.17**	**79.60**	**48.00**	**5.20**	**15.00**
Boxer Cold	**10**	**326.33**	**76.20**	**38.90**	**4.26**	**15.43**
	15	**379.50**	**80.96**	**41.50**	**5.60**	**14.82**
	20	**267.50**	**69.75**	**43.85**	**4.42**	**13.83**
Time Line	**10**	**307.67**	**54.95**	**34.50**	**3.30**	**13.10**
	15	**347.17**	**57.10**	**36.50**	**3.60**	**12.50**
	20	**243.83**	**53.10**	**38.33**	**3.00**	**11.50**
$LSD_{0.05}$ (H × S)		**1.03**	**0.37**	**0.13**	**0.27**	**0.09**

Note: H = Weed-control treatments; S = Inter-row spacing; $LSD_{0.05}$ = Least Significant Difference at the 5% probability level

The outcome from Table (10) shows that the maximum number of spikes was found to be 432.50 spikes per 0.25 m² in the Sonbolatin variety with a distance of 15 cm between the rows of the plants while the minimum number of spikes was recorded by the Buhuth 22 variety at a distance of 20 cm between the rows, where the spikes were its lowest (222.50 spikes per 0.25 m²). Further, the Sonbolatin kind was found to produce the maximum number of grains per spike (77.07 grains), while the Buhuth22 variety at a distance of 20 cm recorded the minimum number of grains (54.02 per spike).

In terms of 1000-grain weight, Sonbolatin variety gave maximum value (46.36 g) at 20 cm row spacing, while the minimum was recorded from Buhuth22 variety at 10 cm row spacing (32.35 g). The maximum grain yield (5.26 $t.ha^{-1}$) was produced from Sonbolatin variety at 15 cm row spacing, opposite to Buhuth22 variety where the minimum grain yield (3.46 $t.ha^{-1}$) was observed at 20 cm row spacing. On the contrary, Buhuth22 variety registered maximum biological yield (15.26 $t.ha^{-1}$) at 10 cm row spacing, whereas Sonbolatin variety recorded minimum biological yield (12.65 $t.ha^{-1}$) at 20 cm row spacing.

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Table 10. Effect of Cultivars and Row Spacing on Yield Traits

Cultivars	Row spacing (cm)	Number of spikes (spikes 0.25 m^{-2})	Number of grains per spike	1000-grain weight (g)	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})
Buhuth22	**10**	**245.00**	**58.65**	**32.35**	**3.66**	**15.26**
	15	**279.83**	**63.70**	**34.50**	**4.35**	**14.85**
	20	**222.50**	**54.02**	**36.50**	**3.46**	**13.26**
Sonbolatin	**10**	**359.42**	**74.45**	**41.65**	**4.56**	**13.85**
	15	**432.50**	**77.07**	**44.00**	**5.26**	**13.05**
	20	**277.50**	**72.20**	**46.36**	**4.24**	**12.65**
L.S.D. V×S		**0.85**	**0.22**	**0.09**	**0.19**	**0.0009**

According to Table (11), Boxer Cold treatment with Sonbolatin cultivar at 15 cm row spacing produced maximum number of spikes which is equal to 455.00 spikes per 0.25 m^2 whereas weedy treatment with Buhuth22 cultivar at 10 cm row spacing represented minimum number of spikes (140.00 spikes per 0.25 m^2). Boxer Cold × Sonbolatin × 15 cm treated combination also gave the highest number of grains per spike (84.90 grains) whereas weedy treatment with Buhuth22 at 10 cm has shown lowest number of grains per spike (41.70 grains).

Boxer Cold × Sonbolatin × 20 cm treatment had the maximum 1000-grain weight of 49.70 g, whereas the weedy treatment of Buhuth22 at 10 cm had the minimum 1000-grain weight of 29.00 g. The maximum grain yield (6.26 $t.ha^{-1}$) was reported by the Boxer Cold × Sonbolatin × 15 cm treatment, while the weedy treatment of Buhuth22 at 20 cm got the minimum grain yield (2.70 $t.ha^{-1}$). The maximum biological yield (17.60 $t.ha^{-1}$) was found by the weed-free treatment of Buhuth22 at 10 cm, while the weedy treatment of Sonbolatin at 20 cm had the minimum biological yield of 11.40 $t.ha^{-1}$.

Constantly relying on a single type of herbicide or herbicides that function similarly can cause the problems of resistant weeds. Hence any effective weed-control system where herbicides play an important role must stand on the combination of herbicides use and row spacing, sowing rate, and sowing time adjusting, as well as proper cultivar selection, right herbicide and its adequate dosage and time of application, herbicide rotation, weed removal, and crop rotation, since these are crucial and effective components of weed management **[30].**

Table 11. Effect of herbicide treatments, cultivars, and row spacing on yield traits

Herbicide treatment	Cultivar	Row spacing (cm)	Number of spikes (spikes 0.25 m^{-2})	Number of grains per spike	1000-grain weight (g)	Grain yield (t.ha^{-1})	Biological yield (t.ha^{-1})
Weedy	**Buhuth22**	**10**	**140.00**	**41.70**	**29.00**	**2.90**	**13.60**
		15	**210.67**	**44.10**	**30.00**	**3.29**	**13.15**
		20	**140.00**	**40.00**	**32.00**	**2.70**	**11.60**
	Sonbolatin	**10**	**319.67**	**61.80**	**35.20**	**3.30**	**12.60**

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		15	**365.00**	**64.00**	**37.00**	**3.50**	**11.80**
		20	**255.00**	**60.00**	**39.10**	**2.90**	**11.40**
Weed Free	**Buhuth22**	**10**	**290.00**	**74.60**	**36.00**	**4.60**	**17.60**
		15	**320.33**	**83.60**	**39.00**	**5.70**	**17.20**
		20	**282.33**	**70.00**	**41.00**	**4.40**	**15.60**
	Sonbolatin	**10**	**400.00**	**92.00**	**49.00**	**7.00**	**15.60**
		15	**500.00**	**95.30**	**52.00**	**7.60**	**14.80**
		20	**300.00**	**89.20**	**55.00**	**6.00**	**14.40**
Boxer Cold	**Buhuth22**	**10**	**280.00**	**70.40**	**33.00**	**4.07**	**16.27**
		15	**304.00**	**77.03**	**36.00**	**4.93**	**15.85**
		20	**250.00**	**60.00**	**38.00**	**3.86**	**14.27**
	Sonbolatin	**10**	**372.67**	**82.00**	**44.40**	**4.46**	**14.60**
		15	**455.00**	**84.90**	**47.00**	**6.26**	**13.80**
		20	**285.00**	**79.50**	**49.70**	**4.97**	**13.40**
Time Line	**Buhuth22**	**10**	**270.00**	**47.90**	**31.00**	**3.10**	**13.60**
		15	**284.33**	**50.10**	**33.00**	**3.50**	**13.20**
		20	**217.67**	**46.10**	**35.00**	**2.90**	**11.60**
	Sonbolatin	**10**	**345.33**	**62.00**	**38.00**	**3.50**	**12.60**
		15	**410.00**	**64.10**	**40.00**	**3.70**	**11.80**
		20	**270.00**	**60.10**	**41.00**	**3.10**	**14.40**
L.S.D. H×V×S			**1.58**	**0.48**	**0.19**	**0.38**	**0.09**

The data shown in Table (12) illustrates that the Boxer Cold Treatment attained the mean highest herbicide efficiency index (10.63) among treatments, contrasting the weedy treatment that produced the mean lowest herbicide efficiency index (0.00). Among the cultivars, the Sonbolatin cultivar's herbicide efficiency index (3.78) was statistically higher than the Buhuth22 cultivar's value, which was measured at a mean of 2.13. As for the row spacing, the herbicide efficiency index was the highest (5.87) at the distance of 15 cm, and the 20 cm spacing had the lowest index (1.39).

According to the assessment of the impact of various herbicide treatments and cultivars, the combination of Boxer Cold and Sonbolatin cultivars has demonstrated the highest average herbicide efficiency index (13.49). In contrast, the herbicide efficiency index in the case of Time Line × Buhuth22 combination was the lowest (−0.24). Also, with respect to the interactions between herbicide treatments and row distance, the herbicide efficiency index for Boxer Cold cultivar at an inter-row distance of 15 cm was found to be the highest (21.95) as compared to Time Line cultivar with an index equal to −0.25. The analysis of cultivar and inter-row spacing interactions revealed that the average herbicide efficiency index for Sonbolatin at an inter-row distance of 15 cm turns out to be the highest (7.91), while the index for Buhuth22 cultivar at an inter-row distance of 20 cm is found to be the lowest (1.01).

Finally, the maximum herbicide efficiency index in the tri-factor interaction

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is shown by Boxer Cold × Sonbolatin × 15 cm combination (29.77), while the combined use of Time Line × Buhuth22 × 10 cm has been given the minimum value of index (−0.51).

Table 12. Effect of individual factors and their interactions on weed control efficiency and yield

Weed control treatments	Varieties	Row spacing (cm)	10	15	20	Mean
Weedy	Buhuth22		0.00	0.00	0.00	0.00
	Sonbolatin		0.00	0.00	0.00	0.00
Weed free	Buhuth22		1.00	1.00	1.00	1.00
	Sonbolatin		1.00	1.00	1.00	1.00
Boxer Cold	Buhuth22		5.70	14.13	3.45	7.76
	Sonbolatin		5.62	29.77	5.09	13.49
Time Line	Buhuth22		-0.51	0.19	-0.40	-0.24
	Sonbolatin		0.00	0.86	1.02	0.63
Mean of weed control treatments			1.60	5.87	1.39	
L.S.D			1.93	3.73		
Weed control treatments	Row spacing (cm)	10	15	20	Mean	
Weedy		0.00	0.00	0.00	0.00	
Weed free		1.00	1.00	1.00	1.00	
Boxer Cold		5.66	21.95	4.27	10.63	
Time Line		-0.25	0.53	0.31	0.19	
L.S.D		5.31	3.22			
Varieties	Row spacing (cm)	10	15	20	Mean	
Buhuth22		1.55	3.83	1.01	2.13	
Sonbolatin		1.65	7.91	1.78	3.78	
L.S.D		3.60	1.81			
Mean of row spacing		1.60	5.87	1.39		
L.S.D		2.82				

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CONCLUSION

Weed management must constitute a combination of control methods, since using only one practice may lead to the development of herbicide resistance, making it less effective in the future. Uncontrolled weeds compete with wheat for water, light, and nutrients, which will decrease yield while increasing production costs.

The results showed that Boxer Cold was the only treatment successfully controlling weed and improving most of the growth and yield parameters. Some yield components were also positively affected by the Sonbolatin variety, while 15 cm row spacing led to the highest mean number of heads, grain number per head, and grain yield overall. Thus, combining proper herbicide application with the suitable cultivar type and row spacing will allow achieving improvement of the wheat productivity.

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