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Integrated Weed Management in Wheat Fields Using Reduced Herbicide Doses Combined with Allelopathic Extracts from Wild Barley (*Hordeum spontaneum* Koch.)

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ABSTRACT

Weed infestation greatly decreases the productivity of wheat fields, commonly controlled by the application of synthetic herbicides. Nonetheless, the ecological impacts of these chemicals have caused interest in studying alternate methods, such as using plant extracts with allelopathic activity. This experiment was conducted at two locations (Location I - Erbil Directorate of Agricultural Research / Ainkawa and Location II - farmer land in Gwer sub-strict) to evaluate the effectiveness of utilizing wild barley aqueous extracts in mixing with lower dosages of synthetic herbicides to control weeds in wheat fields (***Triticum aestivum*** L.) and examine their impact on wheat growth parameters. The study randomly completed the block design (RCBD) with three replications in a field experiment. The treatments contained various combinations of herbicide dosage and wild barley extracts. The treatments comprised a complete application of TARZEC 320 WG herbicide (Halauxifen-methyl 70 g/kg and Pyroxsulam 250 g/kg) at a rate of 90 g/ha, aqueous extracts of wild barley at a concentration of 200 g/L, and mixtures of TARZEC at 75%, 50%, and 25% of the recommended dosage combined with 25%, 50%, and 75% wild barley extracts, respectively, and both of weedy and weed-free plots were used as controls. A significant reduction in weed growth was observed by combining wild barley extracts with lower doses of herbicides. Significant decreases in weed density were noted at the full herbicide dosage in both sites, while the control plots showed the greatest dry weed biomass at each location. The parameters of wheat growth, including plant height, biological yield, weight of 1000 grains, grain yield, harvest index, and weed index, demonstrated significant variations throughout the various treatments. At location II, the weedy control plots showed the highest plant height (111.7 cm). At the same time, the weed-free plots at the same location produced the highest biological yield, reaching a record 19.52 tons per hectare. The plots tested with TARZEC and wild barley water extracts yielded the highest values for thousand-grain weight, grain yield, harvest index, and weed index. Combining allelopathic water extracts from wild barley with herbicide applications may result in a reduction exceeding 50%, thereby enhancing weed management and increasing wheat yield parameters.

Keywords: Allelopathic, reduced herbicide, Triticum aestivum, weed control efficiency.

1 Introduction

Weed plants are the main constraint in crop production in the Kurdistan Region. To protect such valuable cereal crops from some noxious weeds that eventually grow alongside such valuable crops. Lately, allelopathy has been developed as a branch of science that deals with interfering with weeds upon crops or vice versa. Thus, allelopathy covers the beneficial and harmful biochemical interactions. Exudates, leachates, and residues of plants have been reported to be the source of the allelochemicals that affect the growth of other plants[1]. The primary factors affecting cereal crop production are biotic and abiotic. Weeds are considered biotic factors because they negatively affect grain growth, yield, and quality through competition and allelopathy[2,3]. Weed species that most commonly threaten economic stability on wheat farms in Iraq are wild barley (***Hordeum spontaneum***), wild oats (***Avena fatua***), canary grass (***Phalaris minor***), rigid ryegrass (***Lolium rigidum***), ryegrass (***Lolium temulentum***), wild mustard (***Brassica nigra***), cow cockle (***Vaccaria pyramidata***) and Syrian cephalaria (***Cephalaria syriaca***) [4,5]. Weeds have unfavorable effects on the growth and development of companion crops due to the interference relationship, which includes competition and allelopathic interactions[6]. Weed causes 45% yield loss in wheat crops; therefore, programmed control processes are pursued for managing different weed species worldwide, whereas the total

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cost of yield loss and chemical control weeds in the United States of America could approach 15 to 20 billion dollars[7]. As a result, researchers and the Kurdish farming community place a high value on wheat[8]. The main causes of low wheat yield and food security are threats in Kurdistan: high weed infestation, delayed sowing, poor nutrition, and drought[9,10]. Uncontrolled weeds significantly reduce crop yields, particularly in wheat and other field crops[11,12]. Nowadays, there is a data shortage in the Kurdistan Region concerning the effect of weed infestation on gross yield. Chemical weed control is a highly efficient approach to suppressing weeds, and herbicides significantly improve crop productivity by effectively controlling weeds[13]. A potential approach to decrease herbicide usage is to utilize natural substances and manipulate allelopathy to enhance crop quality and conserve the environment[14]. Allelopathy is a phenomenon of nature in which some organisms (such as plants) produce a substance that inhibits nearby plants[15]. Most plants exert allelopathic effects on germination, growth, and development of other plants by releasing allelochemicals into the soil. These chemicals can originate from living organisms or the decomposition of plant residues[16]. Some plants are inhibited by toxins derived from green manure or plant residues that have been returned to the soil to improve the soil[17]. In a greenhouse study of fresh roots with both root and shoot of sunflower residue incorporated into the soil, it was found that they exhibited allelopathic effects on the germinations and growth of wild barley (***Hordeum spontaneum* Koch**.). They notably hindered germination, reduced plant height, and reduced weight compared to the control treatment (without residue). In contrast, a laboratory experiment revealed that different parts of the sunflower plant have varying degrees of toxicity[18]. Utilizing allelopathic plant extracts as herbicides shows great potential for using allelopathy in weed management[19,20]. [21-23] argue that biosynthesized herbicides are safer than synthesized herbicides due to their high biodegradability. According to[23], natural compounds have numerous advantages compared to synthetic ones. In the words of [24], natural products have a short half-life, meaning they are considered safe in terms of environmental toxicology. Plant chemicals with allelopathic activity are often derived from secondary metabolites in the shikimic acid, acetate, or terpenoid pathways[1,25]. Triketone, cinmethylin, bialaphos, glufosinate, and dicamba are natural products used as commercial herbicides. Sorgoleone, artemisinin, and ailanthone are three compounds with herbicidal activity but not commercially used [26]. Allelochemicals can be released from the living plant into the environment through precipitation (such as rainfall, snow, dew, mist, etc.) [27]; in addition, plant residues can be incorporated into the soil either by mulching them on the surface or by mixing them directly into the soil[28]. The main factor that contributes to the overall weed-suppressing effect of barley when used as a cover crop, mulch, or "smother crop" in crop production systems is the release of water-soluble allelochemicals from the plant's reproductive components[28-30]. Allelochemicals are highly concentrated in the allelopathic mulch of barley residues, specifically near the soil surface. This creates an "allelopathic zone" that effectively inhibits the germination of weeds and/or the growth of their seedlings[31]. Allelopathic substances are compounds emitted into soil or aquatic ecosystems as fresh barley plant residues or mature straw decompose[32,33]. However, due to the complicated nature of the soil environment and the resident microbial community, it can be difficult to identify the specific decomposition products that cause the allelopathic effects of incorporated barley residues[34]. An important area of research is isolating and identifying compounds involved in allelopathy. This research aims to develop natural herbicides or growth regulators with unique mechanisms of action that can be more effective than existing herbicides, which weeds have become resistant to[35]. Considering the complete set of allelochemicals present in barley plants is crucial due to their synergistic effects on weed growth[36,37]. To develop efficient herbicides derived from natural chemicals, gathering data on the concentrations and combinations of allelochemicals is crucial. The practical application of allelopathy for weed control includes crop rotations, intercropping, allelopathic mulches, and using allelopathic plant water extracts. Combining allelopathic water extracts with herbicides has a synergistic effect, allowing for a reduced herbicide dosage[38]. The reduction of herbicide usage could be achieved by combining allelopathic water aqueous extracts with lower dosages of herbicides. These issues are influenced by technological, economic, and political factors[39]. Immoral herbicide use can have severe detrimental effects, not only on crops but also on the agro-environment. This includes the promotion of herbicide resistance in weed plants, as well as contamination of soil and irrigation water. Moreover, incorrect application of chemical herbicides can lead to the extermination of non-target organisms, potentially disrupting the ecological balance of the area[40,41].

2 Materials and methods

2.1 Study Site

The field experiments were carried out during the winter season 2021-2022 at two locations [Location I - Erbil Directorate of Agricultural Research / Ainkawa (coordination 36°15'07.7"N 43°59'50.3"E, with altitude 418 m above sea level)] and [Location II - farmer land in Gwer sub-strict (coordination 36°08'46.1"N 43°39'54.4"E altitude of 273 m above sea level)], forty kilometers southwest of Erbil city, Kurdistan Region of Iraq. The Erbil Directorate of Agricultural Research/Ainkawa analyzed soil samples from both experimental locations for some physicochemical properties, and the results are shown in (Table 1). A computerized meteorological station recorded meteorological data from the end of 2021 until mid-2022 (Table 2).

2.2 Experimental Design

The experiment used a randomized complete block design (RCBD) with three replications. Each plot had a size of 2m width and 3m length and contained ten rows of wheat with a row spacing of 20 cm. The distance between plots and replications was one meter. Two factors were examined in this study. The first factor involved wheat plots with two levels of interference. The first level, Wheat Pure Stand (WPS), consisted of weed-free plots that were manually weeded. This treatment was applied to plots at Location I on February 3rd, 2022, and at Location II on February 4th, 2022. The second level, Weedy Check (WCH), involved wheat plots that were left untreated and allowed to grow with weeds. The second factor involved the combination of aqueous extracts with herbicide for weed control tank mixing applications, with six levels of interference.

Table 1: The chemical and physical characteristics of soil samples collected from the studied locations Ainkawa (I) and Gwer (II).

Physical and Chemical Properties		**Location I**	**Location II**
Particle size distribution (g kg^{-1})	Sand %	19	22.1
	Silt %	43	52.1
	Clay %	38	25.8
	Texture	Silty clay loam	Silty loam
EC(Ds/m)		0.3	0.5
pH		7.86	7.65
Available N%		0.11	0.11
Available P (PPM)		8.62	21.5
Available K (PPM)		200	320
O.M%		0.9	0.8

Table 2: Monthly meteorological information, including temperature, humidity, and precipitation for the locations of Ainkawa and Gwer during the 2021-2022 season.

Years	**Location**	**Location I**					**Location II**				
	Months	Min. temp. (°C)	Max. temp. (°C)	Avg. temp. (°C)	Rainfall (mm)	Average relative Humidity %	Min. temp. (°C)	Max. temp. (°C)	Avg. temp. (°C)	Rainfall (mm)	Average relative Humidity %
2021	Nov.	3.27	28.94	15.67	5.4	43.262	10.1	24.1	15.9	4.3	39.3
	Dec.	-0.46	21.59	10.06	74.1	67.82	5.4	15.8	9.6	57.5	54.5
2022	Jan.	-4.52	16.72	6.92	80.5	71.9	3.4	11.6	7.0	56.6	67.9
	Feb.	-0.53	23.64	11.39	28.1	58.34	6.8	18.4	12.1	10.1	53.6
	Mar.	-1.6	26.98	11.46	13	52.32	6.8	17.8	11.9	11.3	50.6
	Apr.	3.94	33.4	20.57	25.4	37.01	14.6	29.1	21.9	20.5	33.7
	May	8.98	40.09	24.25	22.1	32.96	17.5	31.9	25.0	18.1	29.3
Total rainfall					248.6	Total rainfall				178.4	

a) Control (No tank mixing was used for weed control)
b) (100% Herbicide TARZEC 320 WG (Halauxifen-methyl 70 g/kg + Pyroxsulam 250 g/kg) at 90 g. ha-1 Label dose)
c) (100% Wild barley aqueous extracts at a rate of 200 g L^{-1})
d) (TARZEC %75 of dose label + Aqueous extracts wild barley 25%)
e) (TARZEC %50 of dose label + Aqueous extracts wild barley 50%)
f) (TARZEC %25 of dose label + Aqueous extracts wild barley 75%).

2.3 Agronomical Practices

Experimental plots were prepared at both locations using a two-step process of plowing, land leveling, and rotavating. In Location I, bread wheat (JAD - a certified variety) was sown on November 26th, 2021, while in Location II, it was sown on November 27th, 2021. The seed rate used was 100 kg per hectare. The application of Di-Ammonium phosphate (DAP) fertilizer at a rate of 120 kg. ha^{-1} was done along with the initial dose of Urea fertilizer at a rate of 60 kg. ha^{-1}. The second dose of Urea is also at a rate of 60 kg. ha^{-1} was added before the flowering stage. Both locations received supplementary watering due to insufficient precipitation during the flowering phase.

2.4 Herbicide Application

Post-emergence herbicides were (Halauxifen- methyl) 70 g/kg. (pyridine Compound) (Pyroxsulam) (Triazolopyrimidine) 250 g/kg. It is a combination of a synthetic auxin-type herbicide (Group O) and an ALS (Aceto-Lactate Synthase) enzyme-inhibiting herbicide (Group B). This product controls plants by disrupting normal growth patterns and/or inhibiting the production of the enzyme essential for producing the certain amino acids needed for normal plant growth. At the same time, aqueous extracts of wild barley have a high allelopathic negative effect on weed plants in the early stages of growth and at the rate of (200 $g.L^{-1}$). The wild barley was collected from the fields when plant herbaceous wild barley with stems and leaves reached the mature stage; the collected plants were cut into pieces about 2-3 centimeters long. Then, they were left to dry in the shade until completely dry. Afterward, they were allowed to air-dry in a shaded area until fully dried. Subsequently, wild barley was pulverized into a fine powder. To prepare aqueous extracts, 50g of wild barley shoots were added to two separate beakers, each containing 50g of the powder. Then, 250 ml of distilled water was added to both beakers. The mixture was left to stand at room temperature (25°C) for 24 hours. Afterward, the liquid was separated from the powder and subjected to centrifugation to remove any remaining solid particles. The resulting liquid, which amounted to 500 ml after centrifugation, was diluted with water to reach a final volume of 1000 ml. This diluted liquid is considered a stock solution with a concentration of 100%, following the procedure outlined by[42]. Herbicide applications were conducted on February 12, 2022, in locations I and II. The applications took place on a calm and warm day, specifically as a post-emergence treatment when the wheat plants were at the (2-3) real leaves and even nodes stage. On the other hand, the weed plants had (3-4) real leaves. A Battery Knapsack 16L pressure sprayer equipped with a T-jet nozzle was employed, and a calibration procedure was carried out to ensure that the same amount of spray was applied to each plot. The spray volume for all treatments was 400 L ha^{-1}.

2.5 Data Recording and Statistical Analysis

2.5.1 Studied Characters of Wheat

The parameters measured in this study include plant height (cm), biological yield (tone. ha^{-1}), weight of 1000 grain (g), grain yield (tone. ha^{-1}), harvest index (HI %), and weed index (WI %). The estimation is based on the equation provided by[43].

Weed Index (WI%) = seed yield of weed-free − seed yield of treated plot divided by seed yield of weed-free.

2.5.2 Studied Characters of Weeds

Plant density of weeds (m^{-2}); the removed weed plants have been classified and quantified based on the number of broad leaves, narrow leaves, and the total number of weeds (Table 3). The study measured weed plants' fresh and dry biomass (g/m^{-2}); these weeds have been classified as broad and narrow-leaf. The fresh weights of the crops or plants were recorded, followed by drying the weeds in an oven set at a temperature of 70 °C for 72 hours. The weights of the narrow and broad-leaf weeds were calculated after they had dried. The weed persistence index was determined using a formula provided by[44] as stated below:

$$WPI = (WDc / WDt) \times (DWt / DWc) \quad (1)$$

Where WDc and WDt were weed density (number per m^2) in control (Weedy check) and treated plots, respectively, while DWt and DWc were dry weeds in the treated and control (Weedy check) plots individually.

Weed control efficiency (%) was evaluated at the maturity stage of the weed species and calculated using the following formula provided by[45]:

$$WCE\% = (WDc – WDt)/ WDc \times 100 \quad (2)$$

WDc indicates the density of weeds in the control plot, measured as the number of weeds per square meter. WDt indicates the density of weeds in the treated plot, which is also measured as the number of weeds per square meter.

Where the survey of the most common weeds in the study area is shown in (Table 3).

2.5.3 Statistical Analysis

The data was analyzed using standard analysis of variance, and means were compared at a 5% significance level using the Duncan test with SPSS version 25 computer analysis, as described by[46,47].

3 Results and Discussion

3.1 The Effects of Interference, Weed Treatments, and the Combinations on the Wheat Growth and Yield Parameters at Both Locations (Ainkawa I and Gwer II)

The data shown in (Table 4) indicates that the combination of herbicide with aqueous extracts of wild barley at different concentrations had a notable impact on various plant characteristics such as height, biological yield, weight of 1000 grains, grain yield, and harvest index at both research sites., the maximum value of plant height (98.47cm) were recorded (100% Aqueous extracts of the wild barley) in weedy check plots at location I, and the minimum value (71.5 cm) in the treated plots with (H %75 of label dose + WB.A.E. 25%) in weedy check interference. In contrast, at location II, the highest plant height (111.7 cm) and (103.39 cm) were observed in weedy check and weed-free plots, respectively. Furthermore, the lowest value (76.55 cm) was observed in (H %75 of label dose + WB.A.E. 25%) weed-free plots.

Table 3: Most common weed plants in locations I and II.

Scientific, family, and English names of weed plants in locations I and II				
Site	Name of Scientific	Name of Family	Name of English	Leaves Morphology
Location I & II	Avena fatua	Poaceae	Wild Oat	Narrow leaves
	Hordeum spontaneum	Poaceae	Wild Barley	Narrow leaves
	Lolium rigidum L.	Poaceae	Rigid ryegrass	Narrow leaves
	Medicago polymorpha L.	Fabaceae	Toothed bur clover	Broad Leaves
	Carthamus oxyacantha	Asteraceae	Wild Safflower	Broad Leaves
	Silybum marianum L.	Asteraceae	Milk Thistle	Broad Leaves
	Lactuca serriola L.	Asteraceae	Prickly lettuce	Broad Leaves
	Centaurea pallescens	Asteraceae	Knapweed	Broad Leaves
	Daucus carota	Apiaceae	Wild carrot	Broad Leaves
	Convolvulus arvensis	Convolvulaceae	Field bindweed	Broad Leaves
	Malva parviflora	Malvaceae	Cheese-weed mallow	Broad Leaves
	Brassica napus	Brassicaceae	Mustard plants	Broad Leaves
	Raphanus raphanistrum	Brassicaceae	Wild Radish	Broad Leaves
	Capsella bursa-pastoris	Brassicaceae	Shepherd's purse	Broad Leaves
Location I	Cyperus rotundus L.	Cyperaceae	Nut Grass	Narrow leaves
	Leontice leontopetalum L.	Berberidaceae	lion's foot	Broad Leaves
	Lactuca virosa L.	Asteraceae	Wild lettuce	Broad Leaves
Location II	Lolium temulentum L.	Poaceae	Darnel Ryegrass	Narrow leaves
	Phalaris minor	Poaceae	Little seed canary Grass	Narrow leaves
	Apera spica-venti	Poaceae	Windgrass	Narrow leaves
	Xanthium strumarium	Asteraceae	Rough cocklebur	Broad Leaves
	Galium aparine	Rubiaceae	Catchweed	Broad Leaves
	Sinapis arvensis	Brassicaceae	Wild mustard	Broad Leaves

In both locations, plant height was lower in the weed-free treatments than in the weedy check treatments. Competition for resources and a higher density of weeds could be the cause. Allelopathic extracts, in combination with reduced herbicide dosages, have been shown to have a considerable impact on plant height[48]. This study found that one or two sorghum aqueous extracts resulted in shorter wheat plants, similar to Cheema et al. [49]. contrary to the current study, [50] found that combining sorghum, sunflower, and brassica water extract with lower doses of bromoxynil + MCPA increased plant height. Furthermore, the findings presented in (Table 4) demonstrated that all the weed control interventions had a substantial impact on wheat's growth, yield, and yield components. The highest biological yield (17.79 and16.05 tons. ha^{-1}) was recorded in control treatment for both interferences weed-free and weedy check, respectively, at location I, while the lowest value (13.28 and 13.36 ton. ha^{-1}) registered for (100% Aqueous extracts of the wild barley and H %75 of label dose + WB.A.E. 25%) in both weedy check and weed free in location I, even though in the location II the highest number (19.52 ton. ha^{-1}) and (17.85 ton. ha^{-1}) were observed also in control treatment for both weed free and weedy check respectively. During this, the lowest number was recorded in 100% WB.A.E. in weedy check plots and followed by H %25 of label dose + WB.A.E. 75%, which was (14.12 ton. ha^{-1}) and (15.69 ton. ha^{-1}) individually. Herbicides and wild barley water extract sprays have been found to increase biological yield. This is due to a reduction in weed density, which promotes wheat growth and leads to an overall increase in yield. These findings are consistent with the results of [51], who observed that herbicide application was the most effective in reducing weeds and increasing biological yield compared to plots treated with allelopathic water extract. Additionally, [52,53] found that using allelopathic water extracts, either alone or in combination, resulted in higher biological production. Results shown in (Table 4) also explained that the interactions significantly affected 1000 grain weight in both locations; the maximum weight (40.2 g in the control treatment and 38.53 g in Herbicide at 100% label dose) was recorded for weed-free plots in the location I. In contrast, the minimum weight was for control weedy check interference (31.53 g). Regarding location II, the maximum thousand-grain weight was observed for control treatment, and H %25 of label dose + WB.A.E. 75% were (44.1 and 42.4 g) respectively; at the same time, the minimum thousand-grain yield was recorded for weedy check plots, which were control treatment (34.13 g) and H %75 of label dose + WB.A.E. %25 (37.57 g). The outcomes agree with the findings of [50,54-56], who found that combining herbicide dosages and plant water extracts increased 1000-grain weight. The grain yield at location I was 4.88 tons. ha-1 in the control treatment in weed-free plots and the herbicide treatment at 100% label dose in both weed-free and weedy check plots. These two treatments had a statistically similar grain yield and were significantly higher than the 100% WB.A.E. concentration in weed-free plots (3.05 ton. ha^{-1}) and the weedy check control treatment (2.59 ton. ha^{-1}). At location II, the weed-free control treatment achieved the highest grain yield of 5.72 tons. ha^{-1}. This yield was statistically similar to the herbicide treatment at 100% label dose in the weed-free and weedy check plots, which recorded 5.23- and 5.09-tons yields ha^{-1}, respectively. This similarity in yields may be attributed to reduced competition from weeds compared to other treatments. Among the rest of the treatments, the weedy check control treatment had the lowest grain yield (3.36 ton. ha^{-1}) (Table 4).

Similar findings were shown by (Ashraf et al., Awan et al., Afridi and Khan, and Hussain et al.) [53,55-57]; it was observed that the application of herbicides, alongside the combination of water extracts from allelopathic crops and low doses of herbicides, increased grain yield. In terms of harvest index at location I, H %75 of label dose + WB.A.E. %25 and H %50 of label dose + WB.A.E. %50 registered the highest percentage in weed-free plots, which were (90.94 % and 29.15 %) respectively, whereas, the lowest percentage recorded in both weedy check and weed free plots for control and WB.A.E. at 100% concentration which is (16.1 % and 21.8 %) respectively. At the same time, in location II, the maximum rates were recorded (31.24 %) for H %75 of label dose + WB.A.E. %25 in weed-free plots and Herbicide at 100% label dose (31.15%) in weedy check plots. In contrast, the minimum rate registered for control treatment in weedy check plots is (18.81%) (Table 4). The results align with the research conducted by [56,53,59], which demonstrated a notable increase in harvest index when utilizing different concentrated water extracts, including allelochemicals. [60,61] Both found that using herbicides improved all measures, including the harvest index, with the same results in both studies. Results of (Figure 1) for weed index indicate significant impacts of interference and control weed treatments on studied parameters for locations I and II; however, the highest percentage were recorded (21.76 %) and (20.51 %) for WB.A.E. at 100% concentration under weed free plots in both locations. In comparison, the lowest rates were registered for Herbicide at 100% label dose and H %25 of label dose + WB.A.E. %75 in weedy check plots (-73.6 % and -69.31 %) separately at location I. The results correspond with the findings of [51,62-64], who supported using a combination of lower herbicide dosage and allelopathic chemicals for efficient weed control in field crops.

Table 4: The interaction effect of interference and weed control treatments on wheat growth and yield components in Locations I and II.

Location I					
Interference - Weed Free					
	Plant Height (cm)	**Biological yield ($ton.ha^{-1}$)**	**1000 grain weight (g)**	**Grain yield ($ton.ha^{-1}$)**	**Harvest index %**
Weed Control treatments					
Control	91.42cd	17.79ab	40.2bcde	4.88ab	27.45abcd
H. (100%)	72.77hi	15.29bcde	38.53c-g	4.4bcd	28.77abc
WB.A.E. (100%)	90.03cde	14.05cde	36.33fgh	3.05bcd	21.81def
H+WB.A.E. (75%+25%)	75.47hi	13.36e	36.47fgh	4.12bcd	30.94a
H+WB.A.E. (50%+50%)	74.25hi	13.73de	37.53efg	4bcd	29.15abc
H+WB.A.E. (25%+75%)	73.89hi	13.69de	36.23fgh	3.85cd	28.19abcd
Interference - Weedy Check					
Control	98.07bc	16.05bcde	31.53j	2.59cd	16.1f
H. (100%)	71.73i	15.8bcde	35.6ghi	4.4ab	27.93abcd
WB.A.E. (100%)	98.47bc	13.28e	32.8ij	3.11e	23.64bcde
H+WB.A.E. (75%+25%)	71.5i	15.29bcde	33.23hij	3.83bcd	25.01abcd
H+WB.A.E. (50%+50%)	73.64hi	14.64bcde	32.7ij	3.88bcd	26.5abcd
H+WB.A.E. (25%+75%)	73.12hi	14.33cde	31.97j	3.91bcd	27.31abcd
Location II					
Interference - Weed Free					
	Plant Height (cm)	**Biological yield ($ton.ha^{-1}$)**	**1000 grain weight (g)**	**Grain yield ($ton.ha^{-1}$)**	**Harvest index %**
Weed Control treatments					
Control	103.39ab	19.52a	44.1a	5.72a	29.29abc
H. (100%)	77.13ghi	16.95abcd	42.3ab	5.23ab	30.84a
WB.A.E. (100%)	86.13defg	16.85abcd	39.4b-f	3.81ab	22.87cde
H+WB.A.E. (75%+25%)	76.55hi	15.92bcde	41.6abcd	4.97ab	31.24a
H+WB.A.E. (50%+50%)	77.46ghi	16.52a-e	41.7abc	4.88ab	29.63ab
H+WB.A.E. (25%+75%)	81.37efgh	15.69bcde	42.4ab	4.65ab	29.68ab
Interference - Weedy Check					
Control	111.7a	17.85ab	34.13hij	3.36ab	18.81ef
H. (100%)	80.26fghi	16.39a-e	40bcde	5.09ab	31.15a
WB.A.E. (100%)	88.79def	14.12cde	38.4defg	3.83de	27.09abcd
H+WB.A.E. (75%+25%)	76.78hi	17.11abc	37.57efg	4.55ab	26.55abcd
H+WB.A.E. (50%+50%)	77.48ghi	15.87bcde	39.13b-f	4.55ab	28.83abc
H+WB.A.E. (25%+75%)	81.1efgh	15.96bcde	38.67c-g	4.63ab	29.18abc

* Different letters indicate a significant difference using the Tukey test at the 5% probability level. Herbicide (h). Wild Barley Aqueous Extract (WBAE).

3.2 The Effect of Weed Control Treatments on Weed Density Plant (M^{-2}), Fresh and Dry Weed Biomass (G/M^{-2}), and Weed Persistence Index at Two Locations

The data from Table 5 indicates that weed density was significantly affected at locations I and II. Among the various treatments, the control treatment and WB.A.E. at 100% in the location I had the highest weed density, with 70 and 29 plants per square meter, respectively. Conversely, the Herbicide's lowest weed density was observed at 100% label dose and H %50 of label dose + WB.A.E. %50 treatments, with 11 and 13 plants per square meter, respectively. In contrast, in the second location, the highest number of weed density plants was also registered for control treatment, and WB.A.E. at 100% plots, which were (33 and 22 plants m^{-2}), and the lowest number was recorded in both treatments H %50 of label dose + WB.A.E. %50 (10 and 11 plants m^{-2}) respectively. These findings agree with [65,60], who reported that the combined treatment resulted in lower weed density than the weedy check. The crop's weed management effectively suppressed the lower weed population by combining plant aqueous extracts with lowered doses of herbicides[66,67]. It was observed that the total density of weeds was considerably affected by different combinations of aqueous extracts of plants combined with commercial herbicides at minimum concentrations of 70%. According to the data presented in (Table 5), the amount of fresh weed biomass was significantly affected by the treatments that were studied nevertheless the highest fresh biomass weight obtained for control plots in both location I and location II are (960.43 and 516.53 g/m^{-2}) respectively, whereas, the lowest fresh weight was recorded for herbicide treatment at 100% label dose in both location and H %50 of label dose + WB.A.E. %50 in location II with the values (81.17 g/m^{-2}) and (88.83 g/m^{-2}) individually. The combination of allelochemicals and herbicides synergistically enhanced their phytotoxic effects. The findings are consistent with the studies conducted by [56,53]. It was observed that using allelopathic water extracts combined with lower doses of herbicide effectively decreased the fresh weight of weeds. In terms of dry weed biomass (Table 5), the minimum weight recorded (25.77 and 26.9 g/m^{-2}) was in location II, and (27.23 and 32.33 g/m^{-2}) was in location I for herbicide treatment at 100% label dose and H %50 of label dose + WB.A.E. %50. The maximum dry weed biomass in the location I (309.37 g/m^{-2}) and (168.03 g/m^{-2}) was recorded in control treatments and WB.A.E. at 100%. However, in location II, the highest number was noted for the same control and WB.A.E. at 100% treatments with different weights (182.23 and 106.9 g/m^{-2}) separately. Based on the findings, it can be concluded that the efficacy of weed control is enhanced when allelopathic crop water compounds are combined with a reduced concentration of herbicide in a tank. This may result from the potent allelopathic effect of various crop water extracts and the enhanced efficacy of herbicides when allelopathic crop water extracts are combined. This study agreed with [68,61]; they regarded the combination of allelopathic crop water extracts and reduced herbicide concentrations as an efficient method for managing weeds. The present study observed a maximum weed persistence index number (1.31) for WB.A.E. at 100%. In contrast, in the location, I, herbicide treatment at 100% label dose and H %50 of label dose + WB.A.E. %50 showed a minimum number (0.56). Contrary in location II, the lowest weed persistence index was noted in H %75 of label dose + WB.A.E. %25 plots, which is (0.41), while the highest was the same location I as noted in WB.A.E. at 100% treatments with the value (0.88) (Table 5). These results are comparable to [69,51,70,58,63], who showed that the simultaneous application of allelopathic extracts and herbicide doses can result in a significant 75% decrease in herbicide usage. In addition, the study found that the synergistic use of allelopathic water extracts resulted in a 52% increase in efficacy compared to using water extracts alone for weed management in wheat. The efficacy of weed control using allelopathic extracts in conjunction with reduced herbicide doses was variable, owing to differences in weed suppression resulting from the prescribed doses of the different herbicides. Increasing the concentration of allelopathic extracts can enhance the presence of allelochemicals, leading to greater suppression of weeds [44]. While the results in (Figure 2) show that the weed control efficiency had significant effects on weed control treatments for both locations, however, the highest value was observed for control and H %75 of label dose + WB.A.E. %25 plots with rates (84.17 %) and (81.40 %) respectively at location I, even though at the same location the lowest rates for weed control efficiency were noted for plots of H %25 of label dose + WB.A.E. %75 and plots of herbicide treatment at 100% label dose where are (35.63 %) and (58.39 %) respectively. However, at location II, the maximum weed control efficiency percentage was obtained in control and H %25 of label dose + WB.A.E. %75 plots, which is (69.69 %) and (66.64 %) respectively. At the same time, the minimum rates were recorded for herbicide treatment at 100% label dose plot and H %25 of label dose + WB.A.E. %75 plot with the values (33.05 %) and (49.43 %) consecutively. These results align with the findings of [63,67]; their findings indicate that the efficacy of weed management was improved by increasing the amount of herbicide used and combining it with allelopathic water extracts, regardless of the weed species.

Table 5: Effect of weed control treatments weed density plant, fresh and dry weed biomass, and weed persistence index at two locations.

Location I				
	Weed density plant (m^{-2})	Fresh Weed Biomass (g/m^{-2})	Dry Weed Biomass (g/m^{-2})	Weed Persistence Index
Weed Control treatments				
Control	70a	960.43a	309.37a	----
H. (100%)	11de	88.83d	27.23d	0.56c
WB.A.E. (100%)	29b	497.23b	168.03b	1.31a
H+WB.A.E. (75%+25%)	15de	122d	37.6d	0.57c
H+WB.A.E. (50%+50%)	13de	104.87d	32.33d	0.56c
H+WB.A.E. (25%+75%)	17cd	140.77d	43.63d	0.58c

Location II				
Control	33b	516.53b	182.23b	----
H. (100%)	10e	81.17d	25.77d	0.47d
WB.A.E. (100%)	22c	330.57c	106.9c	0.88b
H+WB.A.E. (75%+25%)	13de	98.63d	29.53d	0.41e
H+WB.A.E. (50%+50%)	11de	88.83d	26.9d	0.44de
H+WB.A.E. (25%+75%)	15de	121.2d	36.7d	0.44de

*Different letters indicate a significant difference using the Tukey test at the 5% probability level. Herbicide (h). Wild Barley Aqueous Extract (WBAE).

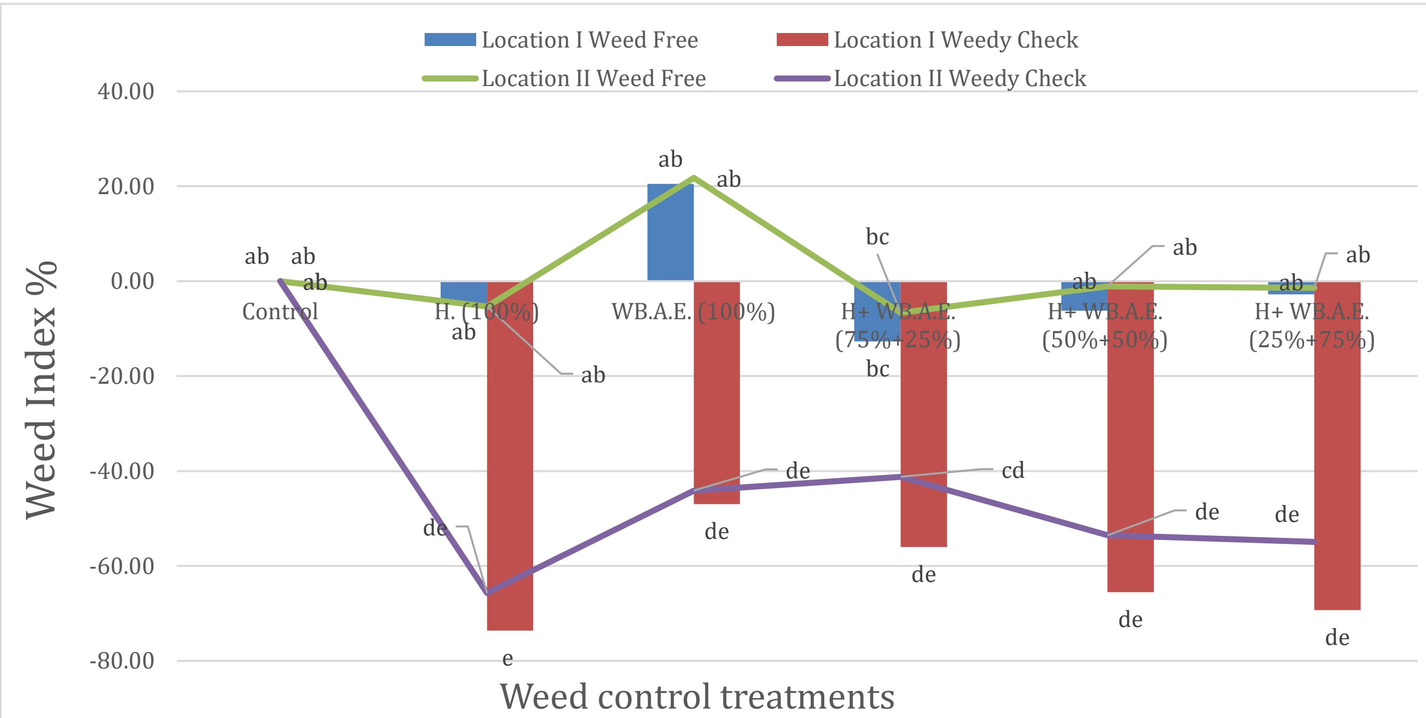

Figure 1: Influence of the weed control of the treatments on weed indexes at two locations. * Different letters mean a significant difference by the Tukey test at a 5 % probability level. Herbicide (H). Wild Barley Aqueous Extract (WB.A.E).

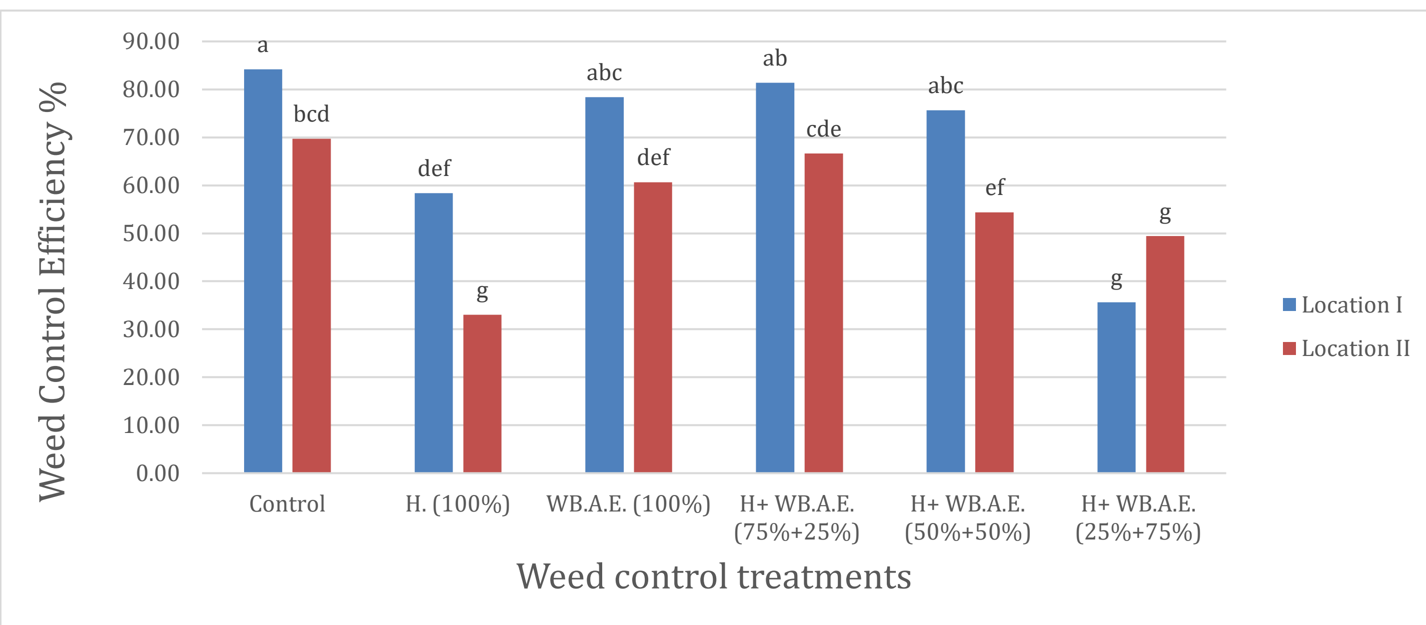

Figure 2: Influence of weed control treatments at two locations on weed control efficiency %. *Different letters indicate a significant difference using the Tukey test at the 5% probability level. Herbicide (h). Wild Barley Aqueous Extract (WBAE).

Conclusion

Wild barley water extracts have been found to impact weed biomass, significantly improving crop yields. It has been noted that when these extracts are combined with a lower dosage of herbicides, they successfully inhibit the growth of weeds. The suppression of weeds is dynamic and enhances several production-related parameters of wheat crops. This integrated approach promotes a healthier crop environment and supports sustainable agricultural practices by potentially reducing chemical usage.

Conflict of interests

None

Author's Contribution

This paper is the part of the first author's PhD dissertation. The first author experimented and collected the data for analysis, while the second author supervised the experiment, including all fieldwork, data analysis, and research paper review.

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