Assessing the Impact of Organic and Chemical Herbicides on Agronomic Parameters, Yield, and Weed Control Efficiency in Lentil (*Lens culinaris* Medik.) under a Direct-Seeding System: A Comparative analysis.

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Abstract. Lentil is characterized by low weed competitiveness due to its small size and slow development, resulting in the reduction of quality and quantity of production. Controlling these weeds with biological alternatives is necessary because lentils are phytotoxic to most herbicides. To address this gap, a field experiment was carried out at the pedagogical research farm of the National School of Agriculture in Meknes, Morocco, for two years, to evaluate the effectiveness of two weeds control strategies; chemical and agroecological. Three treatments, including a Nettle aqueous extract (T3) and two herbicides (Bentazone (T2) and Pyridate (T1)), were compared to the control (T0) in a complete randomized block design with four replications. All treatments resulted in effective weed management in terms of density and biomass, and significant improvement in agronomic parameters compared to the control. However, both herbicides used had a phytotoxic effect on the lentil plants, and the minimum yield was achieved in plots untreated (6.61Qx/ha) followed by plots treated with Pyridate. In contrast, Nettle aqueous extract had no phytotoxic effect, with the highest protein content in the lentil's seeds, the highest economic grain, and a yield almost similar to that of Bentazone. Our study highlights the advantages of using organic Nettle treatment over herbicides for weed control, promoting sustainable agricultural practices. However, further research is needed to explore additional weed control strategies in lentil crops comprehensively.

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1. Introduction

Lentils (*Lens culinaris* Medik.) belongs to the legume family, which plays a technical and economical role at both farm and national levels, it plays an essential agronomic role in crop rotations by increasing the nitrogen content in the soil [1]. Weeds pose a significant biotic threat in agroecosystems, impacting both crop productivity and quality [2]. These weeds cause a reduction in yield from 20 to 49.5% depending on the nature and density of the weeds [3]. [4] reported that losses caused by weeds exceed those caused by any other category of agricultural pest. In terms of overall annual agricultural production, weeds account for 45%, insects for 30%, diseases for 20%, and other pests for 5%. [5], weeds have led to a reduction in lentil yield exceeding 60%. The predominant weed control approach heavily relies on synthetic herbicides [6,7]. Nevertheless, the agricultural dependence on these herbicides is currently giving rise to issues such as health risks, environmental pollution, and the emergence of resistant weed strains [6,7]. The worldwide spread of herbicide-resistant weeds is exponential [8]. Which represents a substantial threat to sustainable agriculture, potentially resulting in diminished crop yields and an escalation in herbicide usage [9]. In addition, Chemical weed control requires a thorough and complete knowledge of the herbicides used and their mode of action, so that they can be applied efficiently and with care [7]. It would therefore be misleading to regard chemical weed control as a miracle cure, without noting that chemical weed control of pulses is a very delicate matter, since crop-selective doses of herbicides do not effectively control broadleaf weeds [10]. To this end, in an experiment field, we proposed a comparative study of the effect of a biological herbicide (extracted from the Nettle *Urtica dioica* L.) and two chemical herbicides; Bentazone and Pyridate on agronomic parameters, weed control efficiency, and yield of lentil crop under direct seeding system. Our study could provide practical recommendations to farmers and help them to make informed decisions regarding the use of these products in their farming system. It can contribute to improving agricultural practices, safeguarding the environment, protecting farmers' health, and promoting agricultural sustainability. It would also provide valuable insights for policymakers, researchers, and farmers in choosing appropriate weed management approaches.

2. Materials and Methods

2.1. Field trial of the experiment

A two-year field experiment spanning the periods 2020-2021 and 2021-2022 was conducted at the research station of the National School of Agriculture in Meknes, Morocco (33°50'46" N, 5°28'49"W, and 547 m above sea level). The experiment followed a randomized complete block design with four replications, conducted under semi-arid conditions. The recorded total rainfall during the growing seasons was 387 mm in 2021 and 285 mm in 2022. The lentil growing season extended from mid-December to the end of May. Soil analysis in the laboratory revealed that the experimental field exhibited a silty-clay-to-clayey texture. The physicochemical properties of the soil are detailed in Table 1.

Table 1. The physicochemical properties of the soil during the two cropping seasons.

Soil characteristics	Cropping Seasons	
Years	**2021**	**2022**
Sands (%)	15.2	14.9
Silt (%)	46.6	43.4
Clays (%)	39.1	38.5
N (ppm)	14.2	11.9
P (ppm)	10.2	12.2
K (ppm)	440.1	420.1
Ph (Water)	7.7	8.1
Total limestone (%)	39.9	39.4
Active limestone (%)	19.3	18.9
Exchange capacity (Cmol kg^{-1})	35.6	34.9
Organic matter (%)	4.4	4.1
Electrical conductivity Ext. 1/5 (ds m $^{-1}$)	0.108	0.105

2.2. Design of experiment

The experience encompasses four treatments, including an aqueous extract from Nettles (T3), and two post-emergence herbicides, Bentazone (T2) and Pyridate (T1), which were compared against an untreated control (T0). The plots, measuring 3.5 m × 3.5 m are composed of six rows of lentils spaced 40 cm apart. Lentil seeds were sown directly in December without tillage, utilizing a conventional seed drill. The seeds were uniformly planted at a depth of 3-4 cm, with a seeding density of 50 kg/ha. The irrigation and all agronomic practices were executed accurately and consistently throughout the two-year, ensuring the reliability of the results.

2.3. Data processing

Table 2 shows the characteristics of the organic and inorganic herbicides tested, which have been applied using a backpack sprayer equipped with slotted nozzles, specific to herbicide treatments, in the inter-rows. Two applications were carried out during the vegetative stage, the nozzle boom was manually maintained 10 cm above the ground during the application, without touching the lentil plants. The Preparation of fermented Nettle extract, weed flora inspection, agronomic parameters, yield, and weed control efficiency were carried out [5]. Several observations were made, in this case, an assessment of the phytotoxicity of the herbicides and the Nettle extract, 15 days after the second application of the treatments using two indices: incidence and severity. Incidence is represented by the number of plants damaged by the treatment as a function of the total number of plants in 5 linear meters per elementary plot (1 meter/line). Severity (intensity): represents the percentage of infected leaves out of the total number of leaves inspected.

Table 2. Characteristics of organic and inorganic herbicides tested.

Treatments	Targeted weeds	Applied dose/ha	Mode of action	Period of Application
Nettle extract	Annual grasses/ Dicotyledo-nous	200 l / ha	Contact (acts on germination) [5,11,12]	Pre-emergence
Lentagran (Pyridate)	Dicotyledo-nous Annual	1 kg/ha (480g/kg of Pyridate)	Contact (acts on Photosynthesis) [13]	Post-emergence
Basagran (Bentazone)	Dicotyledo-nous	1.5 l/ha (480g/l of Bentazone	Contact [13,14]	Post-emergence

2.3.1. Fourier Transform Infrared Spectrometer analysis (FTIR)

Adhering to the methodology [5,15], infrared spectra corresponding to lentil seed proteins were obtained through FTIR analysis. The Fourier Transform Infrared Spectrometer (FTIR) with an ATR (Attenuated Total Reflection) Smart Orbit accessory was employed for this purpose. Ground lentil seeds from each plot were transformed into a powdered form and placed onto the diamond crystal of the ATR-FTIR accessory. Mechanical pressure, facilitated by a turning knob, ensured proper contact for accurate readings. To bolster reliability, three replicate spectra were collected per plot, with three repetitions per sample, yielding FTIR spectra for each treatment. This meticulous approach was adopted to guarantee precision and consistency in the spectral data acquisition process. Subsequently, the obtained results underwent analysis using the "PerkinElmer LS 55" spectrophotometer to identify characteristic peaks and their functional groups. The quantification of protein absorption in the FTIR spectra involved determining the area under the curve. This was achieved by conducting a definite integral within the specified boundaries of two points (1500 and 1700 cm^{-1}) using the "OriginPro® Graphing & Analysis" software. This approach allowed for a precise measurement of the protein absorption region, contributing to a quantitative analysis of the protein content in the lentil seeds [5].

2.3.2. Economic analysis

Economic analysis has been conducted per hectare for one application of all treatments, taking into account the variable costs associated with different materials used and the expenses incurred during the two growing seasons for application: cost of treatment application, cost of treatments, expenses (USD ha^{-1}), unit price (USD Qx^{-1}), revenue (USD ha^{-1}), and profit (USD ha^{-1}). Seed and sowing expenses have been omitted from the analysis due to their uniformity across all treatments. The unit price represents the cost of one quintal (Qx) of lentils in the Meknes region in Morocco for each cropping season. Income is calculated as the unit price multiplied by the yield (Qx per hectare), while Profit is determined by subtracting Expenses (USD per hectare) from Income (USD per hectare). In the treatment involving Nettle extract, 20 kilograms are needed per hectare, the price of the Pyridate herbicide is 75 USD per kilogram, and the price of the Bentazone herbicide is 54 USD per litter, with an application price of 40 USD per hectare for each treatment.

2.4. Statistical analysis

The data from the experiments involving various parameters underwent statistical analysis. Descriptive statistics were calculated using Microsoft Excel 2013, while the analysis of variance (ANOVA) technique was applied using IBM SPSS Statistics 21 software. The data discussed in this analysis encompassed measurements taken during the 2020–21 and 2021–22 cropping seasons. To determine significant differences among treatment means, a post hoc test known as SNK was employed, and statistical significance was defined at a p-value of ≤ 0.05.

3. Results and discussion

3.1 Effect of treatments on weed flora associated with lentil crop

Table 3 shows the weed abundance of various weed species associated with lentils in different treatments in the two years of the experiment. A diversity of species was found in the untreated plots (23 species). The most dominant weed species found in the lentil field were: *Glebionis coronaria* (L.), *Galium aparine* (L.), *Avena stirilis* (L.) *Phalaris minor* (Retz.), and *Bromus rigidus* (Roth.). The lowest abundance is recorded in the plots treated with Pyridate, followed by those treated with aqueous Nettle extract, and lastly, those treated with Bentazone. Bentazone and Pyridate are two selective herbicides used mainly to control broadleaf weeds (dicotyledons) [16], which is the reason why many monocotyledons are found in plots treated with these two herbicides, this is why most studies recommend combining these herbicides with a specific herbicide for monocotyledons, such as pendimethalin [17].

Table 3: Abundance of weed species found in the lentil field for each treatment over the two years of the experiment.

Treatments	T0		T1		T2		T3	
Years	**2021–22**	**2021–22**	**2021–22**	**2021–22**	**2021–22**	**2021–22**	**2021–22**	**2021–22**
Weed flora associated with lentils	**WA (pt/m2)**		**WA (pt/m2)**		**WA (pt/m2)**		**WA (pt/m2)**	
***Polygonum avicular* L.**	18	19	1	1	0	0	0	0
***Convolvulus arvensis* L.**	16	21	0	0	0	0	4	6
***Glebionis coronaria* L.**	65	88	4	3	6	9	9	10
***Calendula arvensis* L.**	14	12	2	1	9	2	2	2
***Papaver rhoeas* L.**	15	13	0	0	1	1	4	5
***Malva parviflora* L.**	18	11	0	0	2	0	2	3
Vaccaria hispanica Mill.	5	9	0	0	0	0	0	2
***Galium aparine* L.**	29	37	5	3	0	2	9	4
***Sonchus oleraceus* L.**	5	4	0	0	0	1	2	3
***Chenopodium album* L.**	5	18	0	0	0	0	3	1
***Bifora testiculata* L.**	5	5	0	1	0	0	4	2
***Helminthotheca echioides* L.**	0	4	0	0	0	0	1	1
***Bupleurum lancifolium* Hornem.**	11	16	1	0	3	0	6	2
***Lamium amplexicaule* L.**	2	2	0	0	0	0	1	2
***Medicago polymorpha* L.**	11	12	0	2	1	0	4	0
***Cirsium arvense* L.**	4	2	0	0	0	0	1	2
***Sinapis arvensis* L.**	3	1	0	1	3	0	0	1
Fumaria parviflora Lam.	3	2	0	0	3	0	0	1
***Avena stirilis* L.**	22	45	11	20	22	25	4	5
***Phalaris minor* Retz.**	22	25	11	22	11	14	3	2
***Bromus rigidus* Roth.**	18	26	6	11	33	26	3	3
***Orobanche ramosa* L.**	3	0	0	0	1	0	0	1
***Silybum marianum* L.**	2	1	0	0	0	0	0	0
Total	295	373	41	65	95	80	62	58

WA: Weed abundance (plant m^{-2}), (T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract**.**

3.2. Incidence and severity of phytotoxicity of treatments applied.

The evaluation of phytotoxicity symptoms (Fig 1) showed that the nettle extract treatment showed no symptoms such as in a previous study [5], while the two anti-dicotyledonous treatments and especially Pyridate showed a phytotoxic effect on lentil plants, followed by Bentazone, these results are confirmed by other previous studies [14], [18-20].

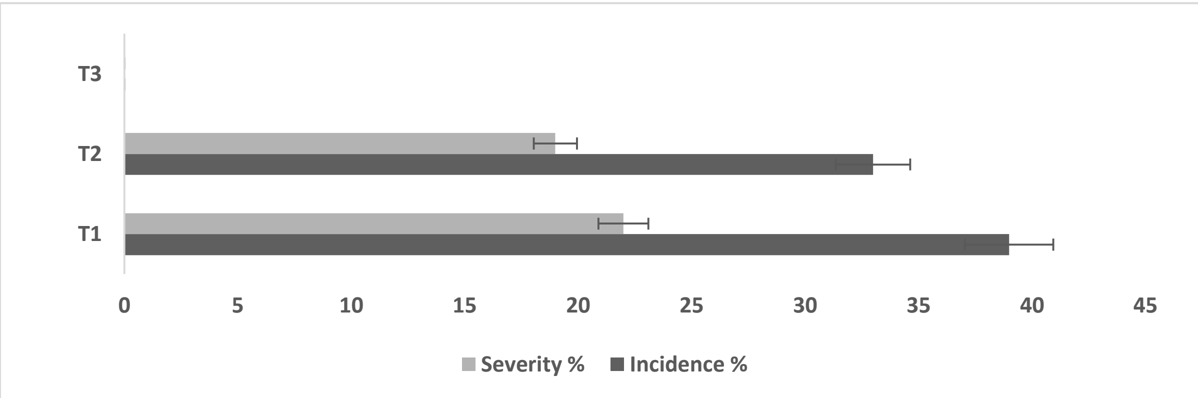

Fig.1. Incidence and severity of phytotoxicity of treatments applied. (T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

3.3. Effect of treatments on weed and crop density.

all treatments provide better and more significant weed management compared to the control (Table 4), the same results were confirmed in previous studies [5,14,18]. The Pyridate treatment contributed to the lowest weed density in both years, but also reduced lentil density because of its phytotoxic effect; the same goes for Bentazone, but with less intensity; the treatment with aqueous Nettle extracts increased lentil density, but with medium weed management.

Table 4: Effect of treatments on weed and crop density at the flowering and the maturity stage.

		Weeds Density (plants m^{-2})		Crop Density (plants m^{-2})	
Growth Stage	**Years / Treatments**	**2020–21**	**2021–22**	**2020–21**	**2021–22**
Flowering stage	**T0**	123 d ± 22.1	221 d ± 24.1	120.12 b ± 10.94	131.17 b ± 9.95
	T1	35.2 a ± 4.2	51 a ± 3.2	100.52 a ± 13.91	99.14 a ± 11.21
	T2	76 c ± 6.87	66 b ± 4.9	141.18 c ± 11.31	130.32 b ± 4.05
	T3	45 b ± 4.6	40.2 a ± 5.2	175.10 d ± 10.11	177.72 c ± 7.42
	***p*-value**	0.002	0.007	0.001	0.002
Maturity stage	**T0**	292 d ± 11.02	373 d ± 33.71	110.01 a ± 7.9	126.86 b ± 9.01
	T1	41.42 a ± 8.18	65 b ± 5.13	100.22 a ± 10.2	87.21 a ± 8.47
	T2	95.1 c ± 9.29	80 c ± 3.30	140.71 b ± 10.32	127.45 b ± 9.19
	T3	62.11 b ± 10.2	58.01 a ± 3.50	172.31 c ± 10.1	167.89 c ± 8.66
	***p*-value**	<0.001	0.002	0.005	0.001

Values represent means, expressed in grams of dry matter (DM) per meter, with the standard error of the mean (SEM). Values sharing the same lower-case letters are not significantly different at a significance level of $p \leq 0.05$. (T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

3.4. Effect of treatments on weed and crop biomass.

Table 5 shows that all of the applied treatments have effectively reduced weed biomass compared to the untreated plots. The Pyridate treatment contributed to the lowest weed and lentil biomass in both years, which explains its effectiveness against dicotyledons [13, 19, 20], followed by the Bentazone treatment. In contrast, the treatment with aqueous Nettle extracts increased lentil and weed biomass.

Table 5: Effect of treatments on weed and crop biomass at the flowering and the maturity stage.

	Cropping season	**2020–21**		**2021–22**	
Growth Stage	**Treatments**	**Weeds biomass (g DM m^{-2})**	**Lentil biomass (g DM m^{-2})**	**Weeds biomass (g DM m^{-2})**	**Lentil biomass (g DM m^{-2})**
Flowering stage	**T0**	731.1 d ± 30.1	99.2 a ± 8.01	679.1 d ± 7.3	90.9 a ± 8.09
	T1	55.7 a ± 8.8	99.10 a ± 10.2	69.9 a ± 1.21	100.5 b ± 10.9
	T2	77.1 b ± 3.1	109.3 b ± 20.4	78.28 b ± 1.26	118.1 c ± 21.1
	T3	105.8 c ± 9.8	139.9 c ± 14.2	127.3 c ± 5.11	137.15 d ± 12.1
	***p*-value**	0.001	0.003	0.009	0.021
Maturity stage	**T0**	801.1 d ± 32.7	56.7 b ± 12. 2	754.3 d ± 10.1	52.23 b ± 8.1
	T1	61.96 a ± 4.2	49 a ± 11.2	71.48 a ± 11	47.26 a ± 5.01
	T2	89. 7 b ± 4.6	65.6 c ± 13.2	93.2 b ± 8.6	78.1 c ± 21.1
	T3	139.1 c ± 21.3	140.2 d ± 10.8	106.1 c ± 15.11	131.5 d ± 18.1
	***p*-value**	0.012	0.005	0.004	0.005

Values represent means, expressed in grams of dry matter (DM) per meter, with the standard error of the mean (SEM). Values sharing the same lower-case letters are not significantly different at a significance level of $p \leq 0.05$. (T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

3.5 Effect of treatments on yield and yield components.

The effect of treatments tested on the yield and yield components of lentils is illustrated in Fig 2, The average yields and the yields of all components are markedly superior compared to the control. All components are significantly higher in plots treated by Bentazone and Nettle extract, and lastly, those treated with Pyridate. The competition between weeds and lentils impacted the growth of lentils, resulting in yield increases of 40,5% (T1), 64.76% (T2), and 65.17 % (T3) compared to the control. The same results were confirmed by other studies; The reduction in lentil yields attributed to weed infestation has been approximated to range between 20% and 80%. [4,5, 21].

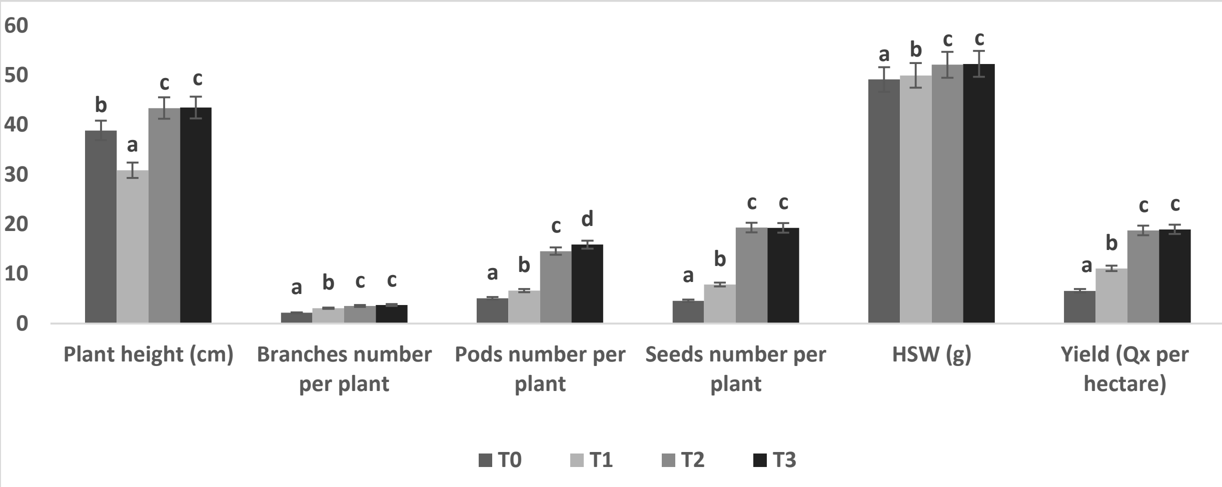

Fig .2. Effect of treatments on yield and yield components.
Histograms represent mean values for lens yield and yield components. Error bars represent standard errors. the data represent the average of the two years of experience, as no significant differences were found between years. HSW: Hundred seed weight. (T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

3.6. Effect of treatments on Weed Control Efficiency (WCE)

Table 6 shows that the most effective treatment tested for weed management is Pyridate with a value of 92.32% in 2020–21 and 90.11 in 2021–22, followed by Bentazone and Nettle extract. Similarly, a study showed that the most effective herbicide for weed reduction is the Pyridate with an efficiency range from 70% to 75% [18, 20]. concerning the efficiency of the Nettle aqueous extract our results are in agreement with others carried out in the same region under the same climatic conditions [5]. The variations in weed control efficacy across different years can be attributed to fluctuations in total monthly rainfall and average monthly temperatures throughout the growing seasons in the study area. The activity and efficacy of herbicides depend on a variety of factors, such as application rate, weed growth stage, nature and type of the weed flora, soil types, climate, and other factors [14, 22, 23].

Table 6: Effectiveness of various weed management treatments in a lentil field.

Treatments	T1		T2		T3	
Years	**2020–21**	**2021–22**	**2020–21**	**2021–22**	**2020–21**	**2021–22**
Flower stage (%)	92.38	89.7	89.45	88.46	85.54	81.25
Maturity stage (%)	92.26	90.52	88.8	87.64	82.64	85.93
Average (%)	92.32	90.11	89.125	88.05	84.09	83.59

(T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

3.7. Effect of treatments on protein content in lentil seeds

The effect of the treatments on the protein content of lentil seeds is shown in Fig 3, and the area of the peaks in the band (1500-1700 cm^{-1}) produced by the Essential FTIR software is illustrated in Table 7 (As the surface area of the peak increases, the protein content of the sample is higher). The presence of weeds frequently influences the protein content in grains more than any other trait [24, 25]. There is a significant difference between all treatments and the control. The Nettle extract has the highest protein content followed by treatment with Pyridate and Bentazone.

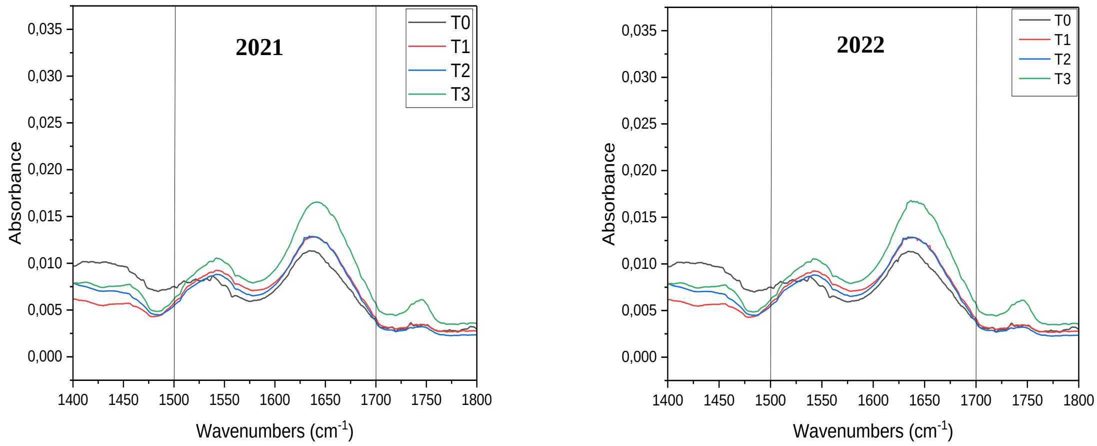

Fig.3. Effect of treatments on protein content. (T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

Table 7: The average area of the peaks in the band (1500-1700 cm^{-1}) is measured using Essential FTIR software.

Years	**2021**	**2022**
Treatment	**Average surface area**	**Average surface area**
T0	0.751	0.743
T1	0.935	0.937
T2	0.931	0.935
T3	1.140	1.142

(T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

3.8. Economic analysis of treatments

Economic analysis of treatments shown in Table 8, the greatest benefit comes from treatment with Nettle extract, followed by the treatment by Bentazone, and in the last Rong the Pyridate treatment. bioherbicides often tend to be more expensive than chemical herbicides but can offer environmental benefits and additional application safety [25, 26, 27], which is why the application costs required by workers in our study are lower than for the two chemical herbicides.

Table 8. Economic analysis of treatments applied in lentils.

Treatments	**Unit cost of treatment (USD)**	**Cost of the application**	**Expenses (USD ha^{-1})**	**Two-year average yield (Qx ha^{-1})**	**Unit price (USD Qx^{-1})**	**Income (USD ha^{-1})**	**Gain (USD $^{-1}$ha)**
T0	-	-	-	6.61	100	661	661
T1	75 USD (1kg ha^{-1})	40 USD ha^{-1}	115 USD	11.11	100	1111	996
T2	81 USD (1.5 l ha^{-1})	40 USD ha^{-1}	121 USD	18.76	100	1876	1755
T3	10 USD (0.5USD kg^{-1})	20 USD ha^{-1}	30 USD	18.98	100	1898	1868

(T0): The control (untreated), (T1): Pyridate, (T2): Bentazone, (T3): Nettle aqueous extract.

4. Conclusion

Lentil crop faces challenges in weed management due to its small size and slow development, which can significantly impact both the quality and quantity of production. Since lentils are often phytotoxic to most herbicides, finding effective and sustainable weed control alternatives is crucial. All treatments tested in this study demonstrated effective weed management in terms of weed density and biomass reduction, as well as significant improvements in agronomic parameters and protein content compared to the untreated control. However, it is noteworthy that both herbicides, Bentazone and Pyridate, exhibited phytotoxic effects on the lentil plants, leading to reduced yields. The complexity of weed species observed in this study suggests that a combination of sequential or integrated treatments may be necessary to achieve more effective weed control and maximize lentil yield. This research also highlights the potential of agroecological approaches, in this case, the use of aqueous Nettle extract, in the management of weeds associated with lentil crops while promoting sustainability and crop quality. Further studies and practical implementations are required to refine these strategies and propose optimal conditions for lentil crops. Within the framework of recommendations, it is crucial to optimize existing treatments by continuing research to reduce the phytotoxic effects of herbicides while maintaining effective weed management. In-depth studies on the sequential or integrated combination of different treatments are also necessary to determine the best strategy for weed management in lentil crops. Concurrently, there is a need to invest in the development of agroecological solutions, exploring different concentrations and application methods of plant extracts such as Nettle. Additionally, educating farmers on best practices for weed management, with a focus on method diversification, is paramount. Lastly, facilitating the exchange of information among researchers, farmers, and decision-makers will contribute to promoting the widespread adoption of best practices in weed management for lentil crops. These recommendations aim to guide future initiatives towards the development of sustainable and effective strategies for weed management in lentil crops.

Implementation of these recommendations begins with a careful exploration of innovative bioherbicide formulations to mitigate phytotoxic effects. The implementation of these formulations is then supported by rigorous practical trials conducted in collaboration with the farming community. These trials, integrated with a thorough methodology, generate essential data that guide the calibration of formulations, seeking to optimize their efficacy while minimizing any undesirable side effects. In parallel, actions such as the organization of interactive forums involving researchers, farmers, and decision-makers, the creation of dedicated online platforms, the development of practical guides for farmers based on trial results, and the encouragement of partnerships between stakeholders contribute to a collaborative ecosystem. Together, these initiatives aim to establish more effective and sustainable weed management in lentil crops.

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