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ORIGINAL ARTICLE

Reduced Corum herbicide dose with allelopathic crop water extract for weed control in faba bean

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Abstract

The aim of this study was to investigate qualitative and quantitative chemical compounds of plant water extract (PWE), and the reduction potential of Corum herbicide (bentazone and imazamox) doses using PWE for weed control in faba bean fields. Chemical analysis revealed the presence of diverse allelochemicals including polyphenols, flavonoids, and terpenoids. The field experiment results showed clear differences between the measured traits in response to the applied treatments. The application of Corum at 1.5 l · ha^{-1}, at 0.75 l · ha^{-1}, and at 0.75 l · ha^{-1} + PWE significantly reduced weed density and biomass, with a weed control efficiency of 75.5–78.4, 57.4–53.3 and 68.2–56.9 % during the first-second cropping seasons, respectively. Meanwhile, Corum at 1.5 l · ha^{-1} and at 0.75 l · ha^{-1} + PWE treatments guaranteed approximately the same yield components and improved the faba bean yield (Q · ha^{-1}) by 65 and 40% in 2018–2019 and by 91 and 85% in 2019–2020, respectively. Therefore, the results suggest that PWE in combination with a lower herbicide dose (up to 50%) could be used as a potential weed management strategy in faba bean. Further research is required to understand the phytotoxic mechanisms of the studied extract-herbicide mixtures and their modes of action.

Keywords: allelopathy, Corum, faba bean, plant water extract, weed management

Introduction

Until the end of the 1970s, Morocco was one of the largest exporters of legumes worldwide, especially faba beans. Unfortunately, this phase weakened over time, and Morocco became an importer in 1992 (Hajjaj *et al.* 2016). Abiotic and biotic factors are major constraints limiting faba bean yield, adding to production unpredictability in Morocco (Karkanis *et al.* 2018). With a decrease of more than 34% in crop yields worldwide, weed losses are higher than those caused by other bio-aggressive crops (Jabran *et al.* 2015). For instance, Moroccan faba bean varieties are sensitive to weed competition for space, water, light, and nutrients (Dawood 2018). The harmful effects of weed species are mainly reflected in quantity and quality losses in harvested yield and/or field re-infestation problems that supplement the soil seed bank (Kubiak *et al.* 2022).

Weed management is crucial to ensure profitable faba bean production. In this regard, hand and mechanical weeding are the most commonly used methods in Morocco. However, they are becoming increasingly expensive and difficult to implement. Moreover, herbicide use appears to be an effective method for increasing crop yields and improving food production (Gianessi 2013). However, with the exception of grass weed herbicides, only one post-emergence broadleaf herbicide, Corum (bentazone + imazamox), has been registered for weed management in faba bean fields in Morocco (Tanji and Elbilali 2018). Furthermore, the harmful effects of herbicides on water sources, diversity, pollinators and humans, environmental health, and the emergence of herbicide-resistant weeds have led to the increased use of chemicals and increasingly complicated weed control processes (Pannacci *et al.* 2017; Sharma *et al.* 2019). Unfortunately, more than 516 herbicide-resistant weed species (including 107 monocots and 148 dicots) have been reported from 94 crops in 71 countries worldwide (Heap 2021).

Overall, it is important to carefully consider the potential effects of herbicide misuse and use them wisely by implementing weed management practices to minimize the frequency and amount used. Herbicide rate reduction refers to the practice of using lower herbicide rates in crop production, which can reduce costs and protect the environment from the adverse effects of excessive herbicide use. However, the relationship between the reduction in the recommended herbicide rate and evolution of resistant ecotypes is a matter of debate. Beckie and Kirkland (2003) reported that reducing herbicide efficacy might contribute to a decrease in the proportion of weed individuals resistant to acetyl-CoA carboxylase (ACCase) inhibiting herbicides. However, other studies have recommended using the recommended rate to minimize the risk of the rapid evolution of polygenic resistance induced at low rates following the progressive accumulation of multiple resistant genes (Busi *et al.* 2012). Thus, industries and growers are concerned about weed problems that may increase as a result of the increased seed bank after herbicide rates are reduced (Blackshaw *et al.* 2006).

To effectively manage herbicide-resistant weeds, integrated pest management strategies that combine multiple control methods are recommended. Furthermore, the search for eco-friendly methods is fundamental to reducing the effects of herbicides. One possible strategy is the use of allelopathic crop extracts as a single strategy or combined with a lower herbicide dose to ensure appropriate weed management and contribute to reducing the problem of weed-resistant ecotypes (Reddy 2017). The combination of allelopathic crop water extracts and low herbicide rates can act synergistically to provide an eco-friendly and economically viable weed control option (Cheema *et al.* 2005; Jabran *et al.* 2008; Jabran *et al.* 2010). Bio-herbicidal properties are mainly due to natural chemical compounds, namely allelochemicals present in plant extracts that exert negative allelopathic effects. Weed inhibition can be attributed to the inhibitory effects of allelochemical compounds or a mixture of molecules belonging to the polyphenol family (Tubeileh and Souikane 2020; Susilo *et al.* 2021). Among the different classes of polyphenols, tannins, phenolic acids, flavonoids, and terpenoids (monoterpenes, phenylpropenes, and sesquiterpenes) are the most important and have often been exploited as natural herbicides that inhibit weed germination and growth (Verma *et al.* 2021).

In this regard, many crop species, such as oat (*Avena sativa* L.), rapeseed (*Brassica napus* L.), and sorghum (*Sorghum bicolor* L.), present bio-herbicidal properties (Chaïb *et al.* 2021; Godlewska *et al.* 2021). Farooq *et al.* (2011) reported that a combination of allelopathic plant extracts was more effective than the application of a single plant extract. Some studies have demonstrated the efficiency of combining plant extracts with a reduced herbicide rate against weed species in field experiments (Alsaadawi *et al.* 2020).

Therefore, the response of faba bean to allelopathic plant extracts might be specific to each agroecosystem. Little information is available regarding weed management in faba bean fields in Morocco. To the best of our knowledge, there has been no scientific study concerning the response of faba bean and weeds to allelopathic crop extracts combined with chemical herbicides. The present study aimed to: 1. Undertake a biochemical analysis (qualitative and quantitative) of oat-rapeseed-sorghum extract (PWE) to determine the main allelochemical groups and contribute to understanding their herbicidal properties and potential applications, and 2. Investigate the possibility of reducing Corum herbicide doses up to 50% in combination with this plant extract for weed management in faba bean fields.

Materials and Methods

Phytochemical screening

Qualitative phytochemical screening of PWE was carried out using different tests based on reagents and inducers by color change or precipitation. The presence of condensed tannins was determined using hydrochloric acid (Broadhurst and Jones 1978). Hydrolyzable tannins (catechic and gallic) are produced using $FeCl_3$ (Karumi 2004). Glycosides are produced using sulfuric acid and acetic acid (Ahmed *et al.* 2019). Flavonoids were prepared using an alkaline reagent (2% NaOH) (Roghini and Vijayalakshmi 2018). The alkaloids were prepared using hydrochloric acid and Dragendroff's reagent (Véronique *et al.* 2021). The determination of terpenoids was carried out using the Salkowski test (Adusei *et al.* 2019). The search for unsaturated sterols was performed by adding sulfuric acid (Alam and El-Nuby 2019). Coumarin compounds were detected using NaOH and UV (Herawati *et al.* 2021). The presence of saponins is indicated by the presence of persistent foam (Adusei *et al.* 2019). Organic acids were detected by the addition of a few drops of bromothymol blue (Alam and El-Nuby 2019). The Libermann-Buchard test was performed for steroids (Véronique *et al.* 2021).

Total polyphenols and flavonoids

The total phenolic compound content in the PWE was determined according to the Folin-Ciocalteu method described by Singleton *et al.* (1999). However, the total flavonoid content of the extract was determined by spectrophotometry according to the method of Lamaison and Carnat descript by Hmid (2013).

Gas chromatography-mass spectrometry (GC–MS)

Quantitative analysis of PWE was carried out using gas chromatography-mass spectrometry (GC-MS) (Rahamouz-Haghighi *et al.* 2022). The oven temperature was initially set at 50°C, and after 5 min, it was increased to 290°C for 10 min. The temperatures of the injector and detector were maintained at 200°C. The mass range was between 40 and 650 AMU, and thus, the ionization energy was approximately 70 eV. The reception and analysis of spectral data were performed using Shimadzu GC-MS solution ver. 4 software (Tokyo, Japan). The chemical compounds were determined based on a comparison of mass spectra with data from NIST 11th edition (National Institute of Standards and Technology, Mass Spectral Library).

Preparation of plant water extract

Three crop species (oat, rapeseed, and sorghum) were selected for this study to prepare allelopathic water extracts. The choice of this species was based on its availability and established allelopathic potential against other plant species (Rigon *et al.* 2012). Water extracts were prepared from the leaves and shoots using the method described by Khaliq *et al.* (2013). The airborne parts of oat, rapeseed, and sorghum were harvested at the maturity stage. After drying, each plant material (at a ratio of 1/3 each dried plant) was crushed to 2–3 cm, soaked in water (1 : 10 and 1 : 5 ratios, weight : volume) for 24 h at room temperature (25 ± 5°C), and filtered through a filter sieve. The extracts were boiled at 100°C to concentrate them for ease of manipulation (Khaliq *et al.* 2013).

Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) was performed to identify the presence of functional chemical groups and to evaluate the composition of the combined aqueous extracts of sorghum, rapeseed, and oats by measuring the absorption of infrared (IR) radiation by each bond in the molecule. FTIR spectroscopy [JASCO FTIR-ATR-4200, JASCO Corporation, Tokyo, Japan)] was performed in the Central Laboratory of the National School of Agriculture in Meknes, Morocco. Therefore, the spectra of the study samples with specified infrared absorption as a function of wave number (cm^{-1}) were recorded between 400 and 4000 cm^{-1} and then processed using PerkinElmer Spectrum Quant software to create graphs from the plotted averages and analyzed using OriginPro® software (Hayat *et al.* 2020).

Greenhouse assay

Plastic pots (20 cm diameter and 18 cm depth) were filled with sandy loam soil and 5% compost. The soil was disinfected using an autoclave to inhibit the germination of other weed seeds and eliminate pathogens. Three seeds of faba bean or field mustard of the same size were sown carefully in each pot. The aqueous extract at two concentrations (1 : 10 and 1 : 5 ratios; weight : volume) was sprayed at 0, 16 and 23 days after seeding (DAS). Pots in the control plots were sprayed with tap water. The plants were harvested at 31DAS, and the germination, height, and fresh and dry biomass of the roots and shoots were determined. The pots were arranged in a completely randomized design with four replicates. The temperature of the experimental chamber was maintained at 22 ± 5°C with a photoperiod of 11/13 h (day/night: 11/13 h).

Field experiment and design

To study the efficiency of PWE mixed with a lower Corum dose, 2 years of field experiments (2018–2019 and 2019–2020) were conducted in a randomized complete block design (RCBD) with four replications under semi-arid conditions of Meknes-Morocco, located in Saïs plateau at about 500 meters above sea level. Precipitation and temperature data during the faba bean growing season are shown in Figure 1. The soil texture was clayey with a low percentage of organic matter (1.36 and 1.26% in the first and second season, respectively), an average rate of mineral nitrogen (25.5 and 21.5 mg · kg^{-1}), a high rate of phosphorus (78 and 76 mg · kg^{-1}) and exchangeable potassium (528 and 556 mg · kg^{-1}). The experimental site was plowed, and the seedbed was prepared using GIL seed

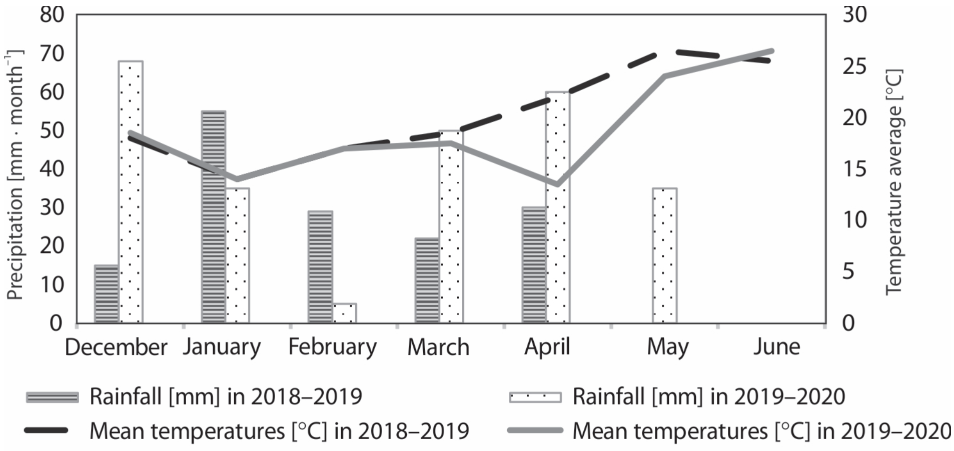

Fig. 1. Total monthly rainfall and temperature averages data from December to June in 2018–2019 and 2019–2020 at the experimental field of the National School of Agriculture, Meknes

drills in 50 cm spaced faba bean rows (seed rate of 100 kg · ha^{-1}).

Treatments

Corum herbicide (Bentazone and Imazamox) was applied in two doses. The first dose was 1.5 l · ha^{-1} (recommended dose), and the second dose was 0.75 l · ha^{-1} (50% of recommended dose) either in combination with or without PWE. These treatments were compared to untreated field plots (weedy check). The debit of the sprayer (spray volume) was 320 l · ha^{-1} determined by calibration. Treatments were applied between faba bean rows using a constant pressure back-sprayer at the post-emergent stage of faba bean (four to five leaves) and weeds (three to five leaves).

Data collection

Weed density and biomass assessment were recorded on two sampling dates (flowering and maturity stages) using squares of 50 × 50 cm, which were randomly positioned in the middle of each plot. Weed dry matter was assessed by cutting faba bean and weeds, which were dried at 105°C for 24 h (Tursun *et al.* 2018). Weed density and biomass results were used to determine the percentage of weed reduction (weed-control efficiency). The relative importance value (RIV) of the main weed species was calculated using the following formula (Baker *et al.* 2018):

$$\text{RIV [\%]} = \frac{\text{Relative frequency} + \text{Relative density}}{2}.$$

The faba bean yield (Q · ha^{-1}) and yield components namely hundred seed weight (HSW), plant height (cm), and the number of pods, seeds, and branches were evaluated at the faba bean harvest stage using 10 plants per plot.

Statistical analysis

The data were analyzed by analysis of variance (ANOVA) and Tukey's multiple comparison tests at the 5% significance level using IBM SPSS Statistics 21 software. The Kolmogorov–Smirnov test was used to check the normality of the data. When the data were not normally distributed, a square root transformation ($\sqrt{x+1}$) was performed before statistical analysis.

Results and Discussion

Phytochemical screening

Qualitative phytochemical exploration revealed the presence of different chemical compounds, especially condensed tannins (proanthocyanidins), alkaloids, flavonoids, unsaturated sterols, coumarins, and terpenoids. Gallic tannins, saponosides, organic acids, and carotenoids were absent. Traces of catechic tannins, glycosides, and steroids were observed in the studied extract (Table 1). Ajani *et al.* (2021) revealed the presence of steroids, terpenoids, glycosides, and alkaloids in sorghum extract, but did not mention the presence of tannins. The revelation of a particular chemical compound depends on the used solvent (water, ethanol, methylol, or ether) (Ajani *et al.* 2021), the involved variety (Shewry *et al.* 2008), and the corroded extraction method (maceration, decoction, infusion, soxhlet, hydro-distillation, etc.) (Nortjie *et al.* 2022).

Total polyphenol and total flavonoid

The content of polyphenols and flavonoids present in the PWE was 1.48 mg of gallic acid · kg^{-1} and 0.67 mg of quercetin · kg^{-1}, respectively. This indicates the richness of the studied PWE in allelochemical

Table 1. Phytochemical screening of plant water extract (PWE)

Chemical compounds		Results	PWE
Condensed tannins		persistent red color	+++
Hydrolyzable tannins	Catechic	green color	++
	Gallic	blue-black color	–
Glycosides		red color	+
Flavonoid		dark yellow color	+++
Alkaloid		orange or red precipitate	+++
Saponosides		persistent foam	–
Organic acids		canary yellow color	–
Steroids		red color	++
Unsaturated sterols		gradual red color	+++
Coumarins		yellow fluorescence	+++
Terpenoid		brown red color	+++
Carotenoids		green blue color	–

(–) – absence, (+) – presence with some traces, (++) – midway present, (+++) – extremely present, PWE

compounds, accompanied by bioherbicide properties. Bodede and Mabelebele (2022) mentioned that sorghum is the richest cereal in phenolic compounds, with an abundance of flavonoids, simple phenolic acids, and tannins. Similarly, Salami *et al.* (2023) showed the richness of rapeseed extract in allelochemical compounds and the importance of genotype and growth stage in the variation of polyphenol and flavonoid content. Furthermore, oat has been identified as a crop species with highly phytotoxic compounds (Xochitl *et al.* 2021).

Gas chromatography-mass spectrometry (GC-MS) analysis

Weed growth inhibition is caused by the inhibitory effects of polyphenol-derived allelochemicals on a given plant extract (Tubeileh and Souikane 2020). According to Susilo *et al.* (2021), the allelopathic properties of sorghum are attributed to scopoleone molecules (sorgoleone), which are secondary metabolites derived from various chemical families. Phenolic acids and scopoletin are significant allelochemicals in oat extract with high weed management potential (Bhadoria 2011). Eight compounds were detected by CG-MS in the studied plant extracts (Table 2). However, D-limonene and gamma-terpinene were the major components of the investigated extract. Flavonoids, phenols, and terpenoids play a primary role in plant-plant interactions and serve as plant signal compounds (Pagare *et al.* 2015). These secondary metabolites have been explored for their use as bioherbicides to inhibit weed germination and growth by disrupting metabolic enzymes, adenosine triphosphate (ATP), hormonal activity, and protein formation and/or by blocking cellular respiration (Verma *et al.* 2021). In addition, Verma *et al.* (2021) mentioned gamma-terpinene and D-limonene as being among the main allelochemical molecules in weeds. Hussain *et al.* (2021) detected other allelochemical molecules in airborne sorghum extracts and root exudates, namely sorgoleone, protocatechuic acid, m-hydroxybenzoic acid, chlorogenic acid, gallic acid, and p-coumaric acid. They reported that sorghum residue exhibits significant

Table 2. Components detected in plant water extract (PWE) using GC-MS analysis

N°	Molecule	Retention time	Peak area [%]	Molecular weight	Molecular formula
1	Alpha-pinene	8.344	0.96	136.23	$C_{10}H_{16}$
2	Sabinene	9.650	0.75	136.23	$C_{10}H_{16}$
3	Beta-pinene	9.834	9.77	136.23	$C_{10}H_{16}$
4	Myrcene	10.230	0.70	136.23	$C_{10}H_{16}$
5	P-cymene	11.480	0.72	134.22	$C_{10}H_{14}$
6	D-limonene	11.662	64.98	136.23	$C_{10}H_{16}$
7	Gamma-terpinene	12.716	8.58	136.23	$C_{10}H_{16}$
8	Thymol	21.253	1.61	150.22	$C_{10}H_{14}O$

allelopathic effects and could reduce weed infestation by up to 95%. Other studies have reported the presence of different chemical compounds in sorghum extract. Ajani *et al.* (2021) reported the presence of 17 molecules with the dominance of organic acids, tocopherols, sterols, esters, and fatty aldehydes. Jing *et al.* (2015) revealed 10 flavonic compounds in rapeseed extracts. However, Georgiev *et al.* (2021) detected the presence of polar, nonpolar, and phenolic compounds in rapeseed meal, with sucrose, melibiose, and turanose (polar compounds), methyl oleate and cetyl alcohol (nonpolar compounds), and sinapic acid as the predominant phenolic acid molecules.

Fourier transform infrared spectroscopy (FTIR) analysis

FTIR is a non-destructive technique designed for molecule characterization through infrared radiation, absorbed in different wavelengths depending on the type of chemical vibration each with specific absorption spectra (peaks or bands) related to different chemical bonds or chemical groups present in the studied sample (Hayat *et al.* 2020; Thummajitsakul *et al.* 2020). Figure 2 shows the FTIR results for the combined aqueous extracts of oat, rapeseed, and sorghum. FTIR analysis revealed 36 distinct peaks with different vibration modes designed for 18 functional groups with medium to high intensity and resolution (Table 3). The frequency of a given vibration varies according to the bond strength, environment of the chemical groups, molecular weight, etc. Several absorption signals with different wavenumbers have been characterized for the functional groups, namely phenols (O-H), methyl groups, carboxylic acids (C-O stretch), aromatics (C-C stretch), aromatic cyanides, nitrile (CN), alkanes, and aldehydes (stretching of C-H bonds). The current bands between 2996 and 3700 cm^{-1} are related to various molecules with O-H and N-H vibrations, suggesting the presence of more than one structural type. The broad peak at 3570–3200 cm^{-1} is related to the O-H stretching vibration of the water molecule, while the other peaks at 2885 and 2985 cm^{-1} are attributed to CH_2 vibrations of lipid clusters and/or alkyl chains (Khan *et al.* 2018; Castiglioni *et al.* 2019). O-H bending of phenol or tertiary alcohol was detected between 1410–1310, and additional signals of phenolic groups were detected around 2260–2500 cm^{-1} (Valenzuela *et al.* 2017). The band of C-H vibrations related to cellulose and/or hemicelluloses could be the origin of the peaks detected at 1075 cm^{-1} (Naumann *et al.* 2010). Most of the absorption bands observed in the fingerprint region between 1660 and 2000 cm^{-1} can be attributed to functional molecules with aromatic compounds.

Greenhouse experiment

The greenhouse experiment was conducted to evaluate the aqueous extract effects of two concentrations (1 : 10 and 1 : 5 ratios, weight/volume) on the germination and early growth of faba bean and field mustard (*Sinapis arvensis*), which gave acceptable germination results (>80%) (Different species dominant in the experimental field had a germination rate less than 10%). The applied plant extract had no significant effect on the fresh biomass, dry biomass, root and shoot length of faba bean. However, highly significant effects were recorded on the length and leaf area of field mustard, as well as on the leaf area of faba bean. The concentration

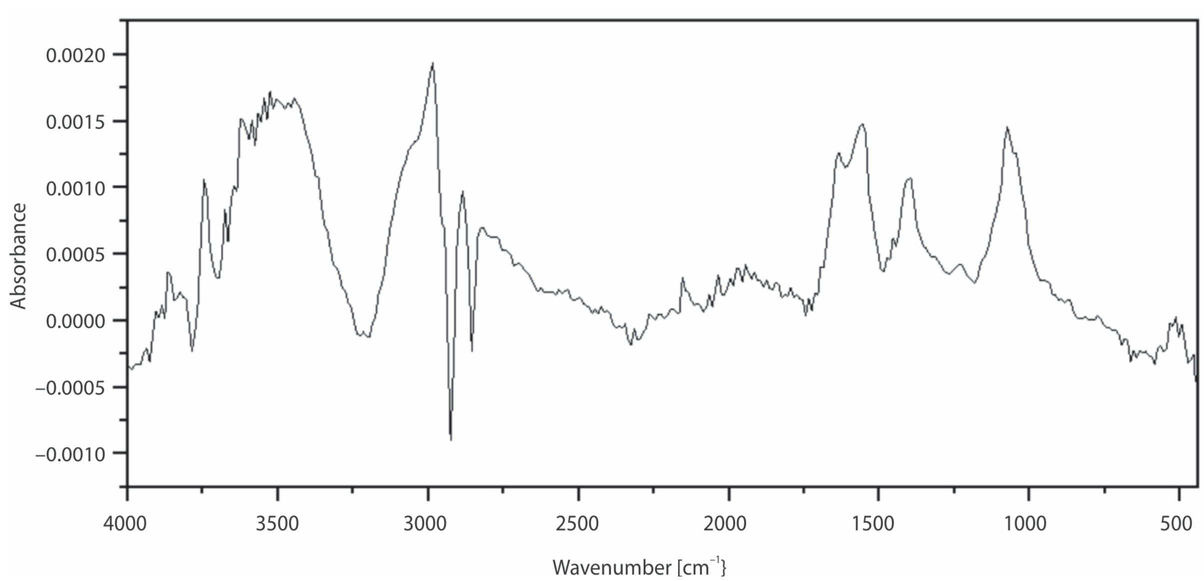

Fig. 2. Fourier transform infrared spectroscopy bands related to the combined oat-rapeseed-sorghum extract

Table 3. Major pics detected using Fourier transform infrared spectroscopy (FTIR) analysis in plant water extraction (PWE)

Mean absorbance peaks [cm^{-1}]	Group frequency wavenumber [cm^{-1}]	Assignment
515 565	600–500	Aliphatic iodo compounds C-I stretch
635	720–590	Alcohol, OH out of plane bend
775	800–700	Aliphatic chloro compounds, C-Cl stretch
811	811	C-H out-of-plane band vibration of alkanes
1075	1185–900	C–O–C, C–O, C–C, C–H of polysaccharides
1235	1270–1230	Aromatic ethers, Aryl –O stretch
1395	1410–1310	Primary or secondary OH bending (in-plane), and phenol or tertiary alcohol OH bend
1555	1610–1550	Carboxylate RCOO
1635	1650–1600	Quinine or conjugated ketone
1795 1845 1875 1915 1945 1975	2000–1660	Aromatic compounds
2035	2140–2100	C≡C terminal alkyne (acetylenic)
2155 2185	2200–2000	Cyanide ion, thiocyanate ion and related ions
2225	2240–2220	Aromatic cyanides; Nitrile (CN)
2265 2315 2345 2425 2495	2260–2500	Phenolic groups
2535 2565 2695	2500–3000	Carboxylic O-H
2815 2885 2985	2996–2800	Stretch C–H of saturated CH
3215 3445	3570–3200	Hydroxyl group H-bonded OH stretch
3525 3615 3745	3700–2996	Stretch O–H and N–H

Assignments are based on studies in the references (Naumann *et al.* 2010; Dhivya 2017; Valenzuela *et al.* 2017; Ying *et al.* 2017; Khan *et al.* 2018)

of 1 : 10 further reduced the growth parameters of *Sinapis arvensis* but significantly improved the leaf area of faba bean (Table 4 and Fig. 3).

The germination kinetics and final germination percentage of field mustard seeds were reduced under the effect of the plant extract by 9 and 40% by applying concentrations of 1 : 5 and 1 : 10 (weight/volume), respectively. However, the latter (1 : 10) had no effect on the final germination percentage of faba bean seeds, despite a slight slowdown in their germination kinetics (Fig. 3).

Relative importance value (RIV) of weed species

The weed flora identified in the first and second cropping seasons were very diverse, with 23 and 30 species, respectively. This species belonged to 19 families. Dicotyledons (broad-leaved) represented more than 93% of the total number of inventoried species. Asteraceae was the most common family in the experimental field.

The relative importance value (RIV) provides an idea of the importance of a given weed species in

Table 4. Leaf area, fresh and dry biomass of *Sinapis arvensis* and *Vicia faba* according to treatments

			Control	Concentration of 1 : 5 [w/v]	Concentration of 1 : 10 [w/v]	*p*-value
Fresh biomass	*Sinapis arvensis*	root	0.023	0.015	0.012	0.242 ns
		shoot	0.316	0.263	0.236	0.780 ns
	Vicia faba	root	1.448	1.286	1.878	0.586 ns
		shoot	2.255	2.108	4.351	0.100 ns
Dry biomass	*Sinapis arvensis*	root	0.0037	0.0026	0.0029	0.621 ns
		shoot	0.035	0.019	0.026	0.438 ns
	Vicia faba	root	0.151	0.171	0.181	0.908 ns
		shoot	0.188	0.184	0.333	0.177ns
Leaf area	*Sinapis arvensis*		23.229 a	10.718 b	3.929 c	<0.001
	Vicia faba		36.216 c	85.488 ab	119.087 a	0.028

Means within a line followed by the same letter are not different according to Tukey's test at $p = 0.05$; ns – not significant

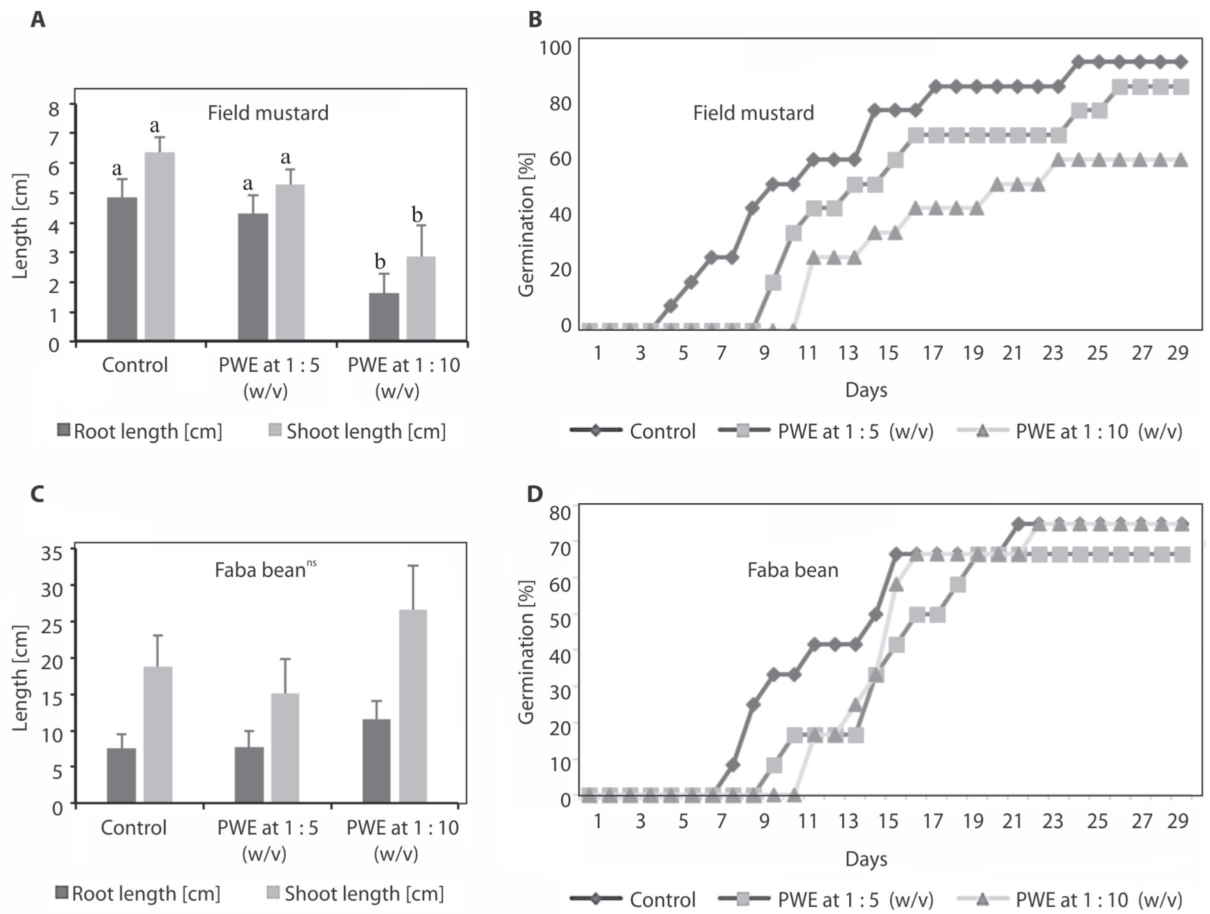

Fig. 3. Effects of aqueous extracts on the growth and seed germination of field mustard (A and B) and faba bean (C and D). Different letters in each category indicate significant differences between the treatments ($p \leq 0.05$); PWE – plant water extract; ns – not significant

each treatment compared to all weed species. Table 5 shows the mean relative importance value (RIV) of the first seven main weed species (*Polygonum avicular*, *Glebionis coronaria*, *Vaccaria hispanica*, *Sinapis arvensis*, *Papaver rhoeas*, *Chenopodium album*, and *Galium aparine*), the total RIV of these species was between 56 to 90%. During the first cropping season (2018–2019), *Polygonum avicular* had the highest values, whereas in the second season (2019–2020) the weed species of *Glebionis coronaria* had the largest RIV. The other species presented different values depending on the applied treatment and the growing season. Indeed, during 2018–2019, the weedy check plots showed the highest diversity of weed species (21–23 species) with a decreasing order of RIV ranging from *C. album*, *G. coronaria*, to *V. hispanica*, among others. While the application of 50% Corum produced the following RIV order: *V. hispanica*, *G. coronaria*, and *P. rhoeas*, the same results were obtained for the treatment of 50% Corum combined with PWE, except that the fourth place was occupied by *P. rhoeas*. Concerning the application of Corum at 1.5 l · ha^{-1}, the order of RIV was; *V. hispanica*, *S. arvensis* and *G. coronaria*. In addition to the four main species, none of the weeds had an RIV of more than 8%. During 2019–2020, the most diversified plot was the weedy check with 25 to 30 species. The order of RIV in the control and Corum plots at 0.75 l · ha^{-1} + PWE was: *G. coronaria*, *G. aparine*, *V. hispanisa*, then *P. avicular*, etc. However, for the treatment of Corum at 0.75 and 1.5 l · ha^{-1} the order of RIV was: *G. coronaria*, *G. aparine*, *P. avicular*, etc.

Weed control and faba bean biomass

The results in Table 6 indicate a significant effect ($p < 0.05$) of the applied treatments on weed density during the two cropping seasons. The highest weed density was recorded in the weedy check with an average of 600.75 and 224.25 plant · m^{-2} during the first and second cropping seasons, respectively. The treatments significantly reduced the total weed density, especially the application of Corum at 1.5 l · ha^{-1} and Corum at 0.75 l · ha^{-1} + PWE with an average 2-year reduction of 68.91 and 54.61%, respectively (Table 6 and Fig. 4). Despite this decrease in weed density, several weed species remained attached to faba bean crops until harvest. Furthermore, pre-emergence treatments and early-stage interventions are highly important to ensure better weed management in faba bean.

Moreover, all applied treatments reduced weed biomass compared to the control (Table 7). However, the untreated plots (control) had the highest values of weed biomass (534 and 127 g · m^{-2} in 2018–2019 and 2019–2020, respectively). The weed control efficiency was more important than the Corum at 1.5 l · ha^{-1} with reduction percentages of 75.5 and 78.4%, followed by the treatment with aqueous plant extract combined with Corum (0.75 l · ha^{-1}), which reduced the weed biomass by an average of 68.2 and 56.9% in the first and second cropping seasons, respectively. Weed control efficiency was reduced during the second survey (maturity stage), which can be explained by leaching of the active material by rain and/or its degradation by other environmental factors. No significant difference was reported in faba bean biomass between the different treatments during the 2019–2020 cropping season. In 2018–2019 the faba bean biomass was improved by 23, 40, and 47% through the application of Corum at 0.75 l · ha^{-1}, Corum at 0.75 l · ha^{-1} + PWE and Corum at 1.5 l · ha^{-1}, respectively (Table 8).

In this regard, some studies indicate that allelopathic extracts combined with a lower herbicide dose provided the same weed control efficiency as the recommended herbicide dose. Farooq *et al.* (2011) reported that the application of sorghum extract combined with a reduced dose of isoproturon (400 g · ha^{-1}) had the

Table 5. Relative importance value (%) of the main weed species found in field experiments of faba bean during 2018–2019 and 2019–2020 seasons in Meknes region, Morocco

		Polygonum avicular	*Glebionis coronaria*	*Vaccaria hispanica*	*Sinapis arvensis*	*Papaver rhoeas*	*Chenopodium album*	*Galium aparine*	Total [%]
2018–2019	Weedy check	36.75	9.41	7.50	5.93	5.72	9.49	2.50	77.30
	Corum at 0.75 l · ha^{-1}	40.32	9.30	11.20	7.45	8.58	7.63	2.84	87.31
	Corum at 0.75 l · ha^{-1} + PWE	41.44	8.27	10.11	6.90	6.27	6.76	4.29	84.02
	Corum at 1.5 l · ha^{-1}	49.02	6.51	10.74	8.31	8.78	5.74	1.21	90.30
2019–2020	Weedy check	7.50	27.05	8.23	3.57	5.89	1.22	13.30	66.75
	Corum at 0.75 l · ha^{-1}	10.43	34.42	8.34	0.54	4.17	2.09	10.77	70.76
	Corum at 0.75 l · ha^{-1} + PWE	7.06	31.27	9.62	2.19	5.98	0.81	14.36	71.28
	Corum at 1.5 l · ha^{-1}	9.51	32.29	2.22	0.65	0.65	2.64	8.17	56.11

The table represents the mean values of relative importance value

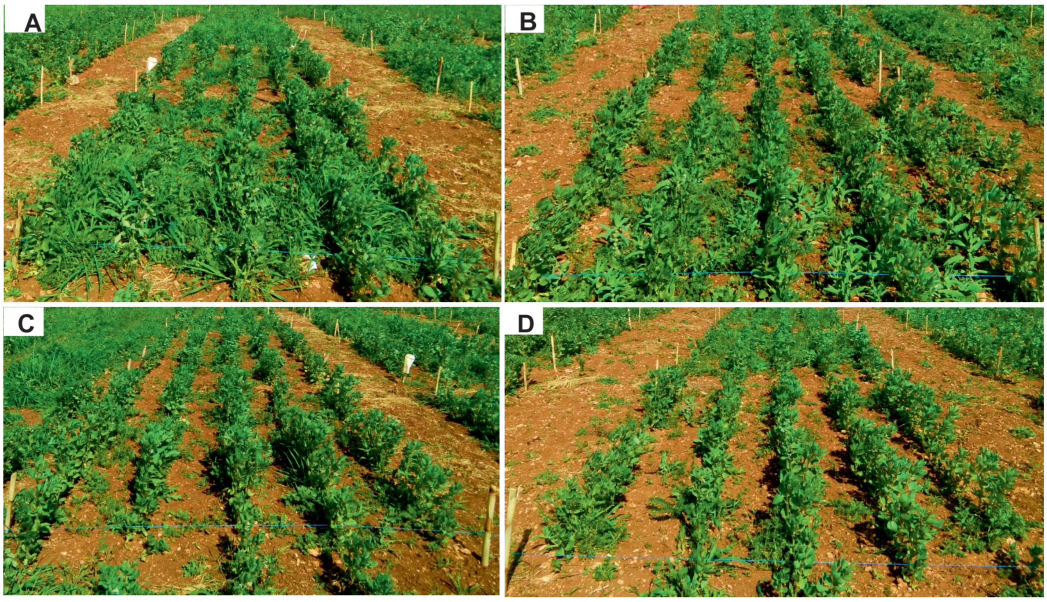

Fig. 4. Visual comparison of weed management using different studied treatments. A – weedy check; B – Corum at 0.75 l · ha^{-1}; C – Corum at 0.75 l · ha^{-1} + PWE (plant water extract); D – Corum at 1.5 l · ha^{-1}

Table 6. Weed density in field faba bean through the application of Corum alone and in combination with plant water extract during 2018–2019 and 2019–2020 cropping seasons

	Total weed density [plants · m^{-2}]					
	2018–2019			2019–2020		
	FS	MS	%R	FS	MS	%R
Weedy check	635.00 a	566.50 a	–	204.00 a	244.50 a	–
Corum at 0.75 l · ha^{-1}	311.50 b	380.00 ab	42.45	96.00 b	112.50b	53.51
Corum at 0.75 l · ha^{-1} + PWE	278.00 b	313.00 b	50.81	91.50 b	95.00 b	58.42
Corum at 1.5 l · ha^{-1}	168.50 b	296.00 b	61.34	48.50 c	57.00 c	76.48
p-value	0.001	0.047		<0.001	<0.001	

The table represents the mean values of total weed density. Means within a column followed by the same letter are not different according to Tukey's test at $p = 0.05$; PWE – plant water extract; FS – flowering stage of faba bean; MS – maturity stage of faba bean; %R – percentage of reduction

Table 7. Effect of Corum alone and in combination with plant water extract on weed and faba bean biomass during 2018–2019 and 2019–2020 cropping seasons

	Total weed biomass [g · m^{-2}]					
	2018–2019			2019–2020		
	FS	MS	%R	FS	MS	%R
Weedy check	533.82 a	534.55 a	–	104.66 a	150.72 a	–
Corum at 0.75 l · ha^{-1}	207.54 b	247.91 ab	57.37	36.25 b	82.88 ab	53.35
Corum at 0.75 l · ha^{-1} + PWE	145.05 bc	194.32 b	68.23	31.03 b	78.99 ab	56.92
Corum at 1.5 l · ha^{-1}	86.72 c	174.53 b	75.55	23.34 b	32.73 b	78.04
p-value	<0.001	0.001	–	0.005	0.012	–

The table represents the mean values of weed biomass. Means within a column followed by the same letter are not different according to Tukey's test at $p = 0.05$; PWE – plant water extract; FS – flowering stage of faba bean; MS – maturity stage of faba bean; %R – percentage of reduction

same weed-control efficiency as the application of a full dose (1 kg · ha^{-1}). In addition, Miri and Armin (2013) showed that sorghum, sunflower, sugar beet, and safflower water extracts at 10 l · ha^{-1} and the application

Table 8. Effect of Corum alone and in combination with plant water extract on faba bean biomass during 2018–2019 and 2019–2020 cropping seasons

	Faba bean biomass [g · m^{-2}]			
	2018–2019		2019–2020	
	FS	MS	FS	MS
Weedy check	38.05 b	71.76 b	12.29	16.74
Corum at 0.75 l · ha^{-1}	59.13 ab	83.84 ab	19.66	25.06
Corum at 0.75 l · ha^{-1} + PWE	74.73 a	108.67 a	21.85	25.79
Corum at 1.5 l · ha^{-1}	84.32 a	121.56 a	21.70	29.69
p-value	0.002	0.021	0.488 ns	0.155 ns

The table represents the mean values of faba bean biomass. Means within a column followed by the same letter are not different according to Tukey's test at $p = 0.05$; PWE – plant water extract; ns – not significant; FS – flowering stage of faba bean; MS – maturity stage of faba bean

of these water extracts in combination with 2,4-D or "Granstar" reduced weed number from 135 to 20 and from 135 to 16 species, respectively. Similarly, Miri and Armin (2013) reported a weed biomass reduction of 60% with allelopathic extracts of sorghum, sunflower, and brassica at 10 l · ha^{-1}. Another study showed that the combination of sorghum and brassica or sunflower extracts with lower glyphosate doses could provide high weed control efficiency (Iqbal *et al.* 2009). The allelochemical effect of plant extracts on weeds can be attributed to a reduction in the content of photosynthetic pigments (chlorophylls and carotenoids), water uptake, electrolyte retention capacity, O2 consumption, enzyme activities, and leakage of electrolyte ions (Ghimire *et al.* 2020).

Faba bean yield and yield components

The faba bean yield components according to different treatments are shown in Table 9. A significant difference was observed between the treatments and weedy check plots, except for the number of branches per plant during the first cropping season. The application of Corum at 0.75 l · ha^{-1} + PWE and Corum at 1.5 l · ha^{-1} resulted in similar yields (Q · ha^{-1}), plant height (cm), pods and seed number per plant. Therefore, faba bean yield was improved compared to weedy check by 12, 40 and 65% in 2018–2019 and by 27, 85 and 91% in 2019–2020 when Corum was applied at 0.75 l · ha^{-1}, Corum at 0.75 l · ha^{-1} + PWE, and Corum at 1.5 l · ha^{-1}, respectively.

Similarly, other studies have revealed that the combination of aqueous plant extracts with a reduced herbicide dose could be an effective method for enhancing rapeseed yield and increasing weed control (Jabran *et al.* 2010). A study pointed out that cotton seeds were improved by up to 21% when the aqueous extracts of sorghum and rapeseed were applied in combination with lower doses of glyphosate (Iqbal *et al.* 2009). Naseem *et al.* (2009) reported that

Table 9. Effect of Corum alone and in combination with plant water extract on faba bean yield and yield components during 2018–2019 and 2019–2020 cropping seasons

		Height [cm]	HSW [g]	BNP	PNP	SNP	Yield [Q · ha^{-1}]
2018–2019	Weedy check	32.84 c	49.31 b	1.63	2.95 b	6.28 b	4.20 b
	Corum at 0.75 l · ha^{-1}	37.50 b	50.39 ab	2.10	4.88 a	10.48a	4.74 b
	Corum at 0.75 l · ha^{-1} + PWE	42.06 a	53.01 a	1.88	4.80 a	11.95a	5.88 a
	Corum at 1.5 l · ha^{-1}	41.05 a	54.33 a	1.85	5.33 a	12.43a	6.93 a
	p-value	0.001	0.015	0.174 ns	<0.001	0.007	0.035
2019–2020	Weedy check	37.29 b	30.41 b	1.56 b	1.67 b	3.44b	2.38 b
	Corum at 0.75 l · ha^{-1}	38.66 ab	35.75 ab	1.97 b	2.83 a	4.65 ab	3.0 3 ab
	Corum at 0.75 l · ha^{-1} + PWE	40.72 a	42.56 a	1.97 b	2.82 a	6.00 a	4.41 a
	Corum at 1.5 l · ha^{-1}	41.01 a	46.84 a	2.03 a	3.28 a	6.06 a	4.55 a
	p-value	0.003	0.037	0.01	<0.001	0.046	0.049

The table represents the mean values of faba bean yield and yield components. Means within a column followed by the same letter are not different according to Tukey's test at $p = 0.05$; PWE – plant water extract; HSW – hundred seed weight; BNP – branches number per plant; PNP – pods number per plant; SNP – seeds number per plant sunflower aqueous extracts have an inhibitory effect against weeds, especially when applied at the pre-emergence stage with increasing application frequency, which significantly increased wheat yield compared to the control.

The differences in weed control efficiency and faba bean yield components between years can be explained by the differences in the total monthly rainfall and temperature averages during the cropping seasons in the experimental field of the studied region. In addition, weed control efficiency of plant extracts and/or herbicides depends on several factors that can vary from one year to another, such as the soil seed bank, weather conditions of days following the application, and weed flora and diversity, etc. (Carrubba *et al.* 020; Naeem *et al.* 2022).

Conclusions

A combined plant extract with reducing herbicide dosage is beneficial for reducing human health risks and minimizing the appearance of herbicide-resistant weeds. Furthermore, it can be used for weed management without heavy contamination of agroecosystems. The current work is the first report describing the effect of a crop water extract combined with a lower dose of Corum herbicide on faba bean and weeds. The results showed a high diversity (23–30 species) of weed species in the experimental fields. The highest relative importance values were recorded for *P. avicular* and *G. coronaria* in the first and second cropping seasons, respectively. The applied treatments decreased the weed population compared to that of the control. The application of Corum 1.5 $l \cdot ha^{-1}$ and 0.75 $l \cdot ha^{-1}$ combined with PWE had the same effect on the yield per unit area ($Q \cdot ha^{-1}$) and a similar effect on the yield components was reported. The results suggest that PWE is an important source of bioactive metabolites that can play a key role in weed management. Also, the field experiments indicated the high potential of combined oat, rapeseed, and sorghum water extracts to reduce the herbicide (Corum) dose by up to 50% in faba bean. This study is the first attempt to explore allelopathic crop extracts combined with a lower dose of Corum herbicide in Morocco. This could be the basis for future studies to further investigate the mode of action and phytotoxic mechanisms of the studied plant extract-Corum herbicide combination.

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