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Faba bean and cereal crop diversification and aphid (*Aphis fabae* Scop.) management in the Meknes region, Morocco

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Abstract

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Black bean aphids are considered a serious pest that can reduce faba bean yield by more than 50%, especially in organic farms. In response to the huge losses caused by aphids, this study aimed to investigate the effect of faba bean-oat and/or wheat intercropping modalities on the incidences and severity of black bean aphids (*Aphis fabae* Scop.). The experiments were conducted in a randomized complete block design with four replicates. The results showed that there was a significant difference in the number of aphids per plant among the sole faba bean crop and the faba bean cereal intercropping systems. The faba bean-oat intercropping at (1:4) ratio significantly reduced the number of aphids per plant, as well as the number of infested plants, with a reduction percentage of 84.44% and 42.42% respectively. However, intercropping faba bean with the two species of cereals at (1:1) ratio did not improve aphid control. Regarding faba bean yield, the intercropping with oat at (1:2) ratio provided the best results and improved the yield crop from 3.76 Q/ha (in sole faba bean) to 8.12 Q/ha (in intercropping system). It was concluded that black bean aphid infestation could be minimized by intercropping practices such as faba bean cereal intercropping. However, the choice of crop species and intercropping modalities is highly important, not only to ensure suitable faba bean productivity but also for sustainable pest management.

Keywords: Black bean aphids; Cereals; Faba bean; Intercropping; Sustainable pest management

Introduction

Sap-sucking aphids belong to the Aphidoidea family and although many species are small and inconspicuous, they can become abundant when conditions are favorable (Mansour et al., 2017). Aphids are serious pests of many crops worldwide because of their complex life cycle, polyphenism, close association with their host plants, and ability to reproduce in different ways (sexual and asexual) (Simon & Peccoud, 2018).

Approximately 4 000 aphid species have colonized different plant families, and the legume family is ranked as the ninth largest family in terms of aphid hosting (Canedo-Júnior et al., 2019). Among the many aphid species, black faba bean aphids (*Aphis fabae* Scop.), which is present worldwide, including in Europe, Western Asia, South America, and Africa (Meradsi & Laamari, 2018). These sap-sucking insects can directly affect plants by causing phytotoxicity when injecting their saliva into the plant phloem or indirectly by transmitting various viruses (275 out of 600 viruses are transmitted by aphids), which cause diseases of major economic importance, or by producing honeydew that promotes the growth of fumaginia, leading to a potential reduction in photosynthesis (Dedryver et al., 2010; Rashedi et al., 2019; Nordey et al., 2021).

This aphid species prefers the tips of newly grown plants to deposit its nymphs (Stoddard et al., 2010). It causes slow growth and leaf distortion, disrupts normal plant development, and results in significant yield losses, which vary depending on the timing of infestation and the incidence and severity of the attack (Almogdad & Semaškienė, 2021). Unfortunately, aphids can quickly reach very high levels of infestation, which is detrimental to host plants mainly because of their short life cycle. Indeed, even newborns contain embryos from their first granddaughter (Singh & Singh, 2021).

To date, pest management, particularly for aphids, is still dependent on nonselective insecticides. Several organophosphate, carbamate, pyrethroid, and neonicotinoid pesticides have been used to control aphids. However, the use of these chemicals has shown severe impacts on insect pollinators (especially bees), human, animal health, agroecosystem balance, as well as adverse effects on the environment in general (Stoddard et al., 2010; Dewar & Denholm, 2017; Serée et al., 2022). In addition, the growing consumer interest in healthy food without chemical pesticides and the emergence of various pesticide-resistant aphid ecotypes (more than two dozen resistant species worldwide) warrant the search for new, reasonable, and sustainable control pathways (Loxdale et al., 2020).

In this framework, several aphid management methods have been used, such as crop rotation, use of biological control agents, and exploration of host plant resistance. However, good agroecological practices minimize intervention and naturally control insect pest populations through bioecological pest management, thereby promoting biodiversity within agroecosystems that can provide a range of ecosystem services, including reducing pest incidence (Allen-Perkins & Estrada, 2019; Rodbell, 2019; Mweke et al., 2020; Sentis et al., 2022).

Intercropping is a common method of crop diversification that can increase herbivorous pest control by promoting the growth of natural pest enemies (predators and parasitoids) and/or by increasing parasitism or predation rates (Allen-Perkins & Estrada, 2019; Liu et al., 2020). To the best of our knowledge, no studies have been conducted on aphid management through crop diversification in Morocco. The objective of this study was to evaluate the effect of different intercropping modalities of faba bean cereals (oat and wheat) on aphid severity and population incidence, as well as on faba bean yield and yield components.

Material and Methods

Crop management and design

The crop association trial was conducted in an experimental field at the National School of Agriculture of Meknes (ENAM). The trial involved associating faba bean cultivation with wheat and/or oats in various spatial arrangements. Faba beans were sown while adhering to the density recommended by farmers in the studied region (110 kg/ha). However, different treatments were developed by adjusting the cereal density from 100% to 25% of the recommended density, which involved planting one, two, three, or four lines of cereal between two lines of beans spaced 0.5 m apart. The cereals were sown a month after sowing faba bean. The trial consisted of four replicates arranged in a randomized complete block design (RCBD).

Incidence and severity of faba bean black aphids

Aphid (*Aphis fabae* Scop.) incidence data were recorded twice (early and late flowering) during the growing season. The aphid population was estimated by observing the terminal portion of ten plants per experimental unit randomly selected from the middle rows of each subplot (marked with a small red cotton thread), and visually scored as the percentage of infested plants (scale 0 = no aphids, 1 = presence of aphids). The same plants were used for aphid attack severity by counting the number of aphids in the terminal 10 cm of each plant.

Yield and yield component of faba bean

Yield measurements were made on faba bean at the mature stage, taking into account different criteria such as plant height, 100-grain weight, and number of gausses, grains, and branches per plant. To do this, 10 random plants were selected and harvested from each elementary plot at the end of the growing season. The plants were then placed in a harvest cage and allowed to dry at room temperature. The height of each plant was measured using a measuring tape, and the number of gausses, kernels, and branches was calculated for each plant. Once the plants were dry, the seeds were harvested from the pods and the weight of 100 kernels was meas-

ured using a scale. The yield per unit area was estimated for each plot at the end of the growing season.

Statistical analysis

As the analysis of variance revealed no significant interaction between the intercropping systems and the growing seasons (years), the data analysis was conducted by combining measurements from both the 2019–20 and 2020–21 cropping seasons. This combined year analysis was performed using mixed models of ANOVA using the SPSS software. Subsequently, Tukey's post hoc analysis was employed to compare the means of the treatments that exhibited a significant impact, with the significance level set at $p = 0.05$. Pearson's correlation analysis was performed to examine the relationships between variables. Graphs were generated using the XLSTAT 2016 software.

Results

Weather conditions

The experimental site was situated in the central-northern region of the country. This location is known for its Mediterranean climate, with some continental influence, favorable rainfall, and suitable soil conditions. The study spanned two cropping seasons, namely 2019–20 and 2020–21. Throughout these seasons, the recorded rainfall was 253 mm in 2019–20 and 386 mm in 2020–21. The total precipitation from December to June during the 2019–20 and 2020–21 cropping seasons was 253 mm and 286 mm, respectively, which fell below the 11-year average precipitation recorded from December 2008 to June 2019 (332.8 mm) for the same period. The average monthly temperatures for the growing seasons of 2019–20 and 2020–21 were 18.7°C and 17.1°C, respectively (Figure 1). Table 1 presents an overview of the soil characteristics (0–25 cm) observed before sowing.

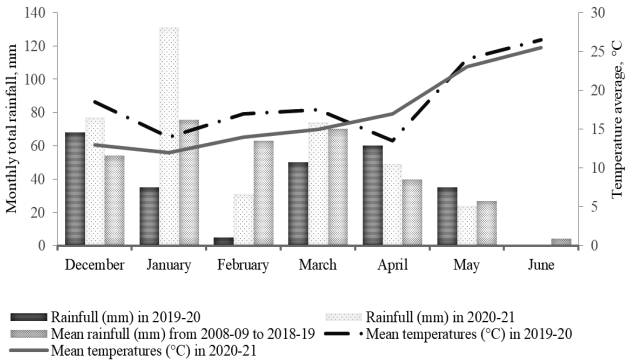

Fig. 1. Weather conditions at the experimental site during the growing season

Table 1. Soil characteristics (0–25 cm) at the experimental site during the growing season

Soil properties	Cropping growing seasons	
	2019–20	2020–21
Physical composition		
Sand, %	17.7	11.8
Silt, %	42.8	51.13
Clay, %	39.7	32.33
Textual class	Clayey	Silty Clay loam
Chemical characteristics		
pH	7.67	7.98
Total nitrogen, %	0.02	0.02
Phosphorus, ppm	48.09	47.89
Organic matter, %	1.26	4.145

Effects of intercropping systems on aphid incidence

The incidence of attack indicated the percentage of aphids on the plant (Figure 2). According to the results obtained, it appears that all the modalities of crop association reduced the average incidence of aphids by 30 and 26%, respectively, for the average of the modalities of bean-oat and bean-wheat association. The incidence increased between the beginning and end of flowering; thus, the highest incidences were obtained in the plots of bean sown in monoculture (82.5%), followed by the bean-cereal type (1:1) with an incidence of 67.5 and 72. Five for oats and wheat, respectively, while the lowest incidence was provided by the faba bean-oat association (1:4), with an average incidence of 47.5% (35% reduc-

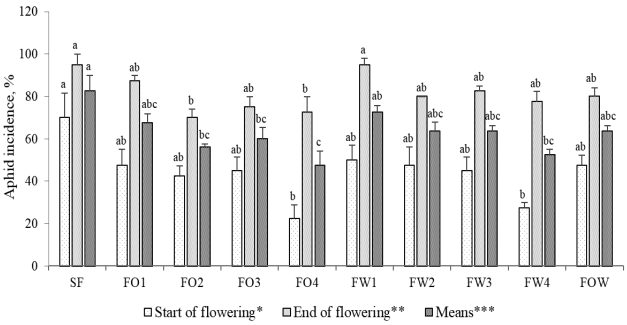

Fig. 2. Intercropping effects on the aphids (*Aphis fabae* Scop.) incidence:

*** indicate significance at $p \leq 0.001$, ** indicate significance at $p \leq 0.005$, * indicate significance at $p \leq 0.01$. SF: sole faba bean. FO1: Faba bean intercropped with oat in (1:1) ratio. FO2: Faba bean intercropped with oat in (1:2) ratio. FO3: Faba bean intercropped with oat in (1:3) ratio. FO4: Faba bean intercropped with oat in (1:4) ratio. FW1: Faba bean intercropped with wheat in (1:1) ratio. F-W2: Faba bean intercropped with wheat in (1:2) ratio. FW3: Faba bean intercropped with wheat in (1:3) ratio. FW4: Faba bean intercropped with wheat in (1:4) ratio

tion compared to the control), followed by faba bean wheat (1:4) with an incidence of 52.5%.

Effects of intercropping systems on aphid severity

Aphid severity was very high in the control, with more than 177 individuals per plant during the second survey, which represents more than double the infestation compared to the early flowering stage of faba bean. The analysis of variance indicated that the severity of aphids was highly significant ($p < 0.001$) between the different association modalities applied. This reflects the impact of the faba bean-cereal intercrop on the number of aphids per plant compared with the faba bean in monocrop system. The intercropping of faba bean with cereals at a ratio of (1:4) significantly reduced the number of aphids per plant, with a percentage reduction of 84.44% and 74.15% in the intercropping with oats and wheat, respectively. However, the lowest percentage of reduction in severity was recorded in the association modality (1:1), with average values of 65.04 and 47.55% (Figure 3).

Effects of intercropping systems on faba bean yield and yield components

The different intercropping systems improved all components of faba bean yield compared to the control, with the exception of the number of sheaves per plant in the case of FO1, FW1, and FW2. In terms of yield per unit area (Q/ha), intercropping significantly improved faba bean yield, especially the faba bean-oat (1:2) combination which provided the best results by increasing yield from 3.76 Q/ha in pure faba bean crop to 8.12 Q/ha in combination. However, the combination of faba bean with both cereal species at a ratio of (1:1) did not result in any yield increase of faba bean (Table 2).

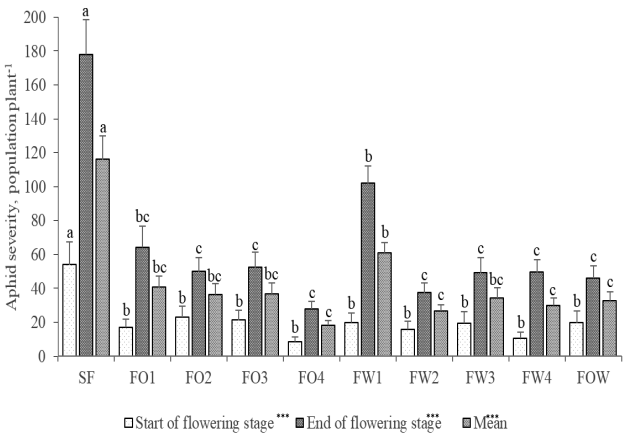

Fig. 3. Intercropping effects on the aphids (*Aphis fabae* Scop.) severity:

*** indicate significance at $p \leq 0.001$. SF: sole faba bean. FO1: Faba bean intercropped with oat in (1:1) ratio. FO2: Faba bean intercropped with oat in (1:2) ratio. FO3: Faba bean intercropped with oat in (1:3) ratio. FO4: Faba bean intercropped with oat in (1:4) ratio. FW1: Faba bean intercropped with wheat in (1:1) ratio. F-W2: Faba bean intercropped with wheat in (1:2) ratio. FW3: Faba bean intercropped with wheat in (1:3) ratio. FW4: Faba bean intercropped with wheat in (1:4) ratio

Correlation between aphids infestation and faba bean yield components

The correlation between 12 parameters (six yield components and faba bean yield and six aphid severity and incidence) is shown in Table 3. Positive and negative correlations were recorded between the different treatments. Negative correlations were observed between aphid infestation param-

Table 2. Yield and yield components of faba bean in different intercropping systems

	HSW	Height	Seeds number	Pods number	Branches number	Yield, Quintal /ha
SF	38.71b	37.10b	4.10c	1.98c	1.37b	3.76b
FO1	45.48ab	41.52a	4.49bc	1.85c	1.61ab	3.81b
FO2	45.84ab	45.01a	8.59a	2.76abc	1.61ab	8.12a
FO3	44.08ab	44.84a	6.28abc	2.70abc	1.62ab	7.20ab
FO4	48.45a	43.20a	4.27bc	3.02ab	1.58ab	6.27ab
FW1	44.55ab	41.52a	5.15bc	1.85c	1.80a	3.74b
FW2	42.41ab	42.70a	6.43abc	1.80c	1.73ab	5.27ab
FW3	44.28ab	41.85a	8.02a	2.38bc	1.73ab	7..39ab
FW4	48.58a	41.82a	6.97ab	3.54a	1.68ab	7.35ab
FOW	45.15ab	43.23a	6.88ab	2.53bc	1.93a	5.38ab
p-value	0.017	0.013	<	<	<	0.048

Means presented within each column with no common letter(s) are significantly different according to Tukey's test where $p \leq 0.05$. HSW: Hundred seed weight. SF: sole faba bean. FO1: Faba bean intercropped with oat in (1:1) ratio. FO2: Faba bean intercropped with oat in (1:2) ratio. FO3: Faba bean intercropped with oat in (1:3) ratio. FO4: Faba bean intercropped with oat in (1:4) ratio. FW1: Faba bean intercropped with wheat in (1:1) ratio. F-W2: Faba bean intercropped with wheat in (1:2) ratio. FW3: Faba bean intercropped with wheat in (1:3) ratio. FW4: Faba bean intercropped with wheat in (1:4) ratio

Table 3. Correlation between aphid infestation and faba bean yield components

	HSW	Height	Seeds Number	Pods Number	Branches Number	Yield	Incidence 1	Incidence 2	Incidence Means	Severity 1	Severity 2	Severity Means
HSW	1											
Height	0.587	1										
Seeds Number	0.221	0.559	1									
Pods Number	0.295	0.304	0.798**	1								
Branches Number	0.354	0.46	0.44	0.241	1							
Yield	0.487	0.657*	0.772**	0.769**	0.083	1						
Incidence 1	-0.936**	-0.59	-0.199	-0.32	-0.245	-0.579	1					
Incidence 2	-0.705*	-0.898**	-0.501	-0.324	-0.339	-0.723*	0.752*	1				
Incidence Means	-0.906**	-0.745*	-0.328	-0.341	-0.297	-0.670*	0.967**	0.894**	1			
Severity 1	-0.855**	-0.682*	-0.254	-0.237	-0.579	-0.387	0.866**	0.684*	0.850**	1		
Severity 2	-0.735*	-0.836**	-0.481	-0.364	-0.539	-0.606	0.792**	0.756*	0.828**	0.901**	1	
Severity Means	-0.775**	-0.816**	-0.438	-0.342	-0.557	-0,567	0.822**	0.753*	0.847**	0.939**	0.995**	1

* Indicate significance correlation at 0.05. ** Indicate significance correlation at 0.01. HSW: Hundred seed weight. 1: the beginning of flowering stage. 2: End of flowering stage.

eters and faba bean yield components, especially for hundred kernel weight and plant length, and significant negative correlations were revealed between aphid incidence (average incidence and late flowering stage) and faba bean yield (Q/ha). However, positive correlations were observed between yield and yield components, particularly between yield (Q/ha) and plant height, number of gausses, and seeds per plant. Similarly, the severity and incidence, on average and during both surveys, showed strong positive correlations.

Discussion

The present study deals with the management of black aphids associated with faba bean in the Meknes region of Morocco. The results of this study show that crop diversification of faba bean with cereals can reduce the incidence and severity of black aphids in faba bean crops, which can lead to an increase in faba bean yield and yield components.

Other studies have confirmed that intercropping faba beans with cereals, such as wheat or barley, can reduce the aphid population, an insect pest that can cause substantial yield losses in crops (Bennour et al., 2021). Intercropping faba beans with cereals can reduce aphid infestation in faba beans for several reasons (Hansen et al., 2008). Intercropping faba beans with cereals can help control aphid pests by enhancing natural predators, reducing the susceptibility to monocultures, accompanying planting, and improving plant resistance. Intercropping can promote the development of natural enemies that prey on aphids, such as predatory ground beetles, spiders, and hoverfly larvae (Saharaoui & Hemptinne, 2009; Gontijo et al., 2018). The diversity of species and plant structures in intercropping systems can create habitats that are more complex and resources for beneficial insects, boosting their activity and abundance (Wang et al., 2009; Huss et al., 2022). These natural predators not only consume aphids but also provide ecosystem services by controlling other pests. In addition, by growing a mixture of plants, the monoculture-sensitive environment is disturbed, reducing the chances of aphids developing in the area and infesting large populations (Liu et al., 2020). Additionally, some cereal plants can deter aphids from feeding by releasing compounds that discourage them. This can disrupt the life cycles of pests and prevent future infestations. Indeed, some cereals, such as parasitoid wasps and ladybug beetles, release volatile substances that repel aphids and attract their natural enemies. Intercropping can improve the nutritional status of faba bean through the complementary use of natural resources (El-Mehy et al., 2022). Cereal crops provide and improve nutrient availability, thus improving faba bean health, which can enhance its resilience and resistance against aphid infestations (Karkanis et al., 2018). However, it is crucial to note that the effect of intercropping on aphids can depend on various factors, such as crop species and cultivars, planting density and layout, timing and duration of intercropping, and prevailing environmental conditions (Salman et al., 2015; Petit et al., 2018).

Interestingly, black faba bean aphids had a significant impact on the yield and yield components of faba bean. Black aphids (*Aphis fabae*) are insect pests that can cause significant damage to faba bean crops. They feed on plant sap, which can lead to decreased plant growth, seed quality, and crop yield (Almogdad & Semaškienė, 2021). Black

aphid infestation reduces the yield and yield components of faba bean crops, including plant height and seed weight. This reduction in faba bean yield in the monoculture can be attributed to infestation by aphids, weed species, and diseases (Zhang et al., 2019; Boutagayout et al., 2023). Intercropping faba beans with cereals has been shown to be an effective strategy for improving the yield and yield components of faba beans. There are several possible reasons for this finding. Intercropping allows both crops to share soil nutrients, water, and other resources, which optimizes their use and improves growth (Zhu et al., 2022). Faba beans and cereals have different physiological functions and growth habits, and intercropping can enhance the complementary effects of these crops (Girma et al., 2019). Third, intercropping increases the biodiversity in the field, which can improve soil health and reduce pest and disease pressures. Finally, intercropping can attract beneficial soil microbiota, which can increase nutrient availability (Bekele & Chemeda, 2022).

This study was also conducted to analyze the correlation between yield parameters and aphid infestation in faba bean crops. The results showed a significant negative correlation between black aphid incidence and faba bean crop yield as well as between black aphid incidence and faba bean crop yield components, including plant height and grain weight. However, it should be noted that the correlation between yield components and black aphid infestation in faba bean-cereal intercropping systems may vary depending on various factors such as crop variety, climatic conditions, and pest management strategies (Rizk, 2011). Previous studies have also shown that black aphid infestation can lead to a reduction in faba bean yield because of its negative impact on plant growth and development (Thobatsi, 2009; El-Zoghby et al., 2022).

The results of this study show that diversification of faba bean crops with cereals can reduce the incidence and severity of black aphids in faba bean crops, which can lead to an increase in the yield and yield components of faba bean crops. This study also highlights the negative impact of black aphid infestation on the yield and yield components of faba bean crops and the correlation between these parameters. These results can help farmers make informed crop management decisions to maximize the yield and quality of faba bean crops.

Conclusion

This study highlights the importance of aphid management in faba beans as well as the positive impact of crop diversification on this management. Furthermore, the results highlight the correlation between aphid incidence and severity, yield, and yield components of faba bean, which can help farmers make informed crop management and variety selection decisions.

Therefore, monitoring and managing black aphid infestations in faba bean-cereal intercropping systems is critical for minimizing faba bean yield losses and reducing costs associated with pest management. Overall, the faba bean-cereal intercrop creates an ecological system that provides black aphid management, better resource utilization, and reliable yield. This technique represents a promising strategy for sustainable agriculture, and can help meet increasing food demands while reducing environmental impacts.

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Authors Contributions

Conceptualization: A.B.; Writing-original draft preparation: A.B.; Provision of samples and field activities: A.B. and W.R.; Statistical application, data analysis: A.B and A.A.; Visualization, A.B., L.N., E.B., and S.B.; Supervision: E.B., and S.B. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

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