

Evaluation of Some Faba Bean Genotypes to Foliar Diseases under Biological, Organic and Mineral Nitrogen Fertilization

Marwa Kh. A. Mohamed^{1*}, Eman I. Abdel-Wahab¹, Nasr A. Ghazy², Walaa S. Elbatrawy³

¹Food Legumes Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt

²Plant Pathology Research Institute, Agricultural Research Center, Giza, Egypt

³Seed Technology Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt

Email: *marwakhil777@yahoo.com

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Abstract

A two-year experiment was conducted at the Sakha Agricultural Experiments and Research Station in the Agricultural Research Center (ARC) in the Kafr El-Sheikh governorate, Egypt, during the 2021/2022 and 2022/2023 seasons. The study aimed to evaluate the resistance of some faba bean genotypes to leaf rust and chocolate spot by applying biological, organic, and mineral N fertilization to enhance seed yield, quality, and farmer's profits. The treatments were the combinations between three fertilization sources (biological, organic, and mineral N fertilization) and eight faba bean genotypes (Giza 40, Giza 716, Sakha 1, Sakha 4, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015). The treatments were laid out in a split-plot design with three replications. Fertilization sources were randomly assigned to the main plots, and the faba bean genotypes were allocated in sub-plots. Mineral N fertilization offered better protection against rust disease in Giza 40 and L2039/437/2015 compared to biological or organic fertilization, while chocolate spot disease was lower after 90 days of sowing with biological fertilization. Rust disease incidence was lower in L2144/379/2015 treated with biological or organic fertilization at 70 and 90 days after sowing. L2103/591/2014 and L2144/379/2015 responded positively to biological fertilization, indicating their resistance to chocolate spots. Biological fertilization showed potential in enhancing foliar disease resistance in Sakha 4, Sakha 1, and Giza 716, leading to potentially higher yields. Giza 40 and L2039/437/2015, which were susceptible to foliar diseases, showed higher productivity with mineral N fertilization. Sakha 1, Sakha 4, L2039/437/2015, and L2144/379/2015 had higher seed protein and carbohydrate contents with organic fertilization, while L2103/591/2014 and L2141/353/2015 showed the same with biological

fertilization. Giza 716 showed greater economic returns with biological fertilization. Giza 40 and L2039/437/2015 demonstrated higher economic returns with mineral N fertilization. L2141/353/2015 had higher economic returns with organic fertilization, while L2103/591/2014 and L2144/379/2015 showed better returns with biological fertilization. Sakha 1, Sakha 4, Giza 716, and L2144/379/2015 treated with biological fertilization demonstrated higher productivity and profit with good quality compared to organic or mineral N fertilizations, suggesting that L2144/379/2015 is a promising genotype in foliar disease breeding programs.

Keywords

Faba Bean Genotypes, Fertilization Sources, Foliar Diseases, Seed Yield, Seed Quality, Economic Return

1. Introduction

Faba bean (*Vicia faba* L.) is a vital pulse crop worldwide, providing a valuable and cost-effective plant protein source for both human and livestock diets [1] [2]. It significantly contributes to restoring soil fertility by fixing atmospheric nitrogen (N) [3]. However, the area under faba bean cultivation in the Nile Valley and Delta region of Egypt has decreased, reaching approximately 47,000 hectares in 2023. The average yield per hectare is 3.42 tons [4]. However, the evolution of various fungal pathogens due to climate change has had a significant impact on faba bean production [5]. Chocolate spot disease, one of the most important faba bean diseases in Egypt, is primarily caused by *Botrytis fabae* Sard. and *Botrytis cinerea* Pers. [6] [7]. The severity of chocolate spot disease was notably higher in northern Egypt, specifically in the governorates of Kafr El-Sheikh, El-Dakahlia, Domiat, and El-Behira [8]. He added that chocolate spot disease can thrive and proliferate more easily in these regions during January and February due to favorable climatic conditions. According to Deneke [9], faba bean yield can be drastically decreased by over 60% during severe outbreaks of chocolate spot disease. Particularly, El-Abssi *et al.* [10] present evidence of using promising faba bean genotypes to enhance agronomic performance stability and resistance to chocolate spot in breeding programs, especially in the face of unpredictable climate changes. On the other hand, faba bean rust (*Uromyces viciae-fabae* Pers.) is a major disease affecting faba beans worldwide, leading to yield losses of up to 70% in early infections [11]. Control methods include the use of fungicides [12] and resistant cultivars [13] [14]. However, due to the high cost and environmental impact of fungicides, as well as the limited availability of fully resistant cultivars, there is a growing interest in exploring alternative management practices. The excessive use of chemical fertilizers has led to the depletion of vital minerals in the soil, disrupting microorganisms and reducing the diversity of soil flora and fauna [15]. Thus, the depletion of essential minerals in the soil can result in decreased crop yields and overall soil

health, emphasizing the need for sustainable alternatives to chemical fertilizers to maintain a healthy ecosystem in agriculture. Particularly, Guo *et al.* [16] revealed that the use of mineral nitrogen (N) application has been linked to an increase in the incidence of chocolate spot. The interactions between plants and microorganisms in the rhizosphere soil play a crucial role in promoting soil health, productivity, and nutrient cycling [17]. Biological fertilization has been used to enhance plant growth by promoting root and shoot elongation, increasing leaf number [18], and ultimately increasing dry matter accumulation during growth and development stages. Moreover, the use of organic fertilizers improves soil quality, enhances root growth, and increases soil microbial activity, leading to high yields and sustainable crop production [19]. In this respect, applications of calcium (Ca), zinc (Zn), and manganese (Mn) have been shown to enhance the activity of chitinase and β -1,3-glucanase enzymes, which can play a role in controlling rust disease in faba beans through the degradation of fungal cell walls [20]. According to Ibrahim [21], compost tea can effectively control chocolate leaf spot disease in faba beans after brewing for six days. Furthermore, it enhances various yield traits, boosts plant disease resistance against fungal pathogens, and promotes soil microbe activity. Current resistance in cultivars is only partial [22], highlighting the need for innovative approaches to combat these pathogens. Particularly, Soliman *et al.* [23] found that faba bean cultivar Giza 40 was more susceptible to rust and chocolate spot compared to others. Thus, developing resistant and high-yielding faba bean genotypes for foliar diseases is crucial for improving productivity, particularly in light of the growing global population and the widespread use of N fertilizers in agriculture. Santamora, L2, Giza 843, Sakha 4, and Sakha 3 genotypes have shown resistance to rust and chocolate spot diseases while also exhibiting high productivity in the Sakha region under mineral N fertilization [24]. Moreover, Abdel-Wahab *et al.* [25] showed that certain legume genotypes can achieve seed yields comparable to those receiving full mineral N fertilization with reduced rates, highlighting the importance of understanding the relationships between legume genotypes and their nutrient sources and sinks [26]. Therefore, the study aimed to evaluate the resistance of some faba bean genotypes to leaf rust and chocolate spot by applying biological, organic, and mineral N fertilization to enhance seed yield, quality, and farmer's profits.

2. Materials and Methods

The experiment took place at the Sakha Research Station (31°06'42"N, 30°56'45"E, 17 m a.s.l.), Agricultural Research Center (ARC) during the 2021/2022 and 2022/2023 seasons. The study aimed to evaluate some faba bean genotypes to leaf rust and chocolate spot by applying biological, organic, and mineral N fertilization to enhance seed yield, quality, and farmer's profits. The treatments were the combinations between three fertilization sources (biological, organic, and mineral N fertilization), also with eight faba bean genotypes (Giza 40, Giza 716, Sakha 1, Sakha 4, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015).

Table 1 provides the common names and pedigrees of the faba bean genotypes under investigation.

Table 1. Common names and pedigrees of the studied faba bean genotypes.

Common name	Pedigree
Giza 40	An individual plant selection from Rebaya 40
Giza 716	416/842/83 x 503/453/83
Sakha 1	Giza 716 x 620/283/85
Sakha 4	Sakha 1 x Giza 3
L2039/437/2015	Giza 843 x 137M/ILB43628
L2141/353/2015	Nubaria 3 x Sakha 1
L2103/591/2014	Nubaria 3 x Giza 7
L2144/379/2015	Nubaria 3 x Nubaria 2

Soil samples were collected from each location at a depth of 0 - 60 cm. Mechanical and chemical properties of the soil (**Table 2**) were conducted following the methodology outlined by Black [27].

Table 2. Mechanical and chemical properties of the soil at the experimental site in both seasons.

Soil properties	Soil depth (0 - 60 cm)	
	First season	Second season
Sand %	9.24	9.13
Silt %	29.60	29.95
Clay %	61.16	60.92
Texture class	Clay	Clay
pH	7.83	7.95
N (ml/kg)	26.72	26.20
P (ml/kg)	9.13	8.80
K (ml/kg)	272	248

Rice was the previous summer crop in both seasons, and 357 kg per hectare of calcium superphosphate (15.5% P₂O₅) was applied during soil preparation in both winter seasons. The treatments were laid out in a split plot design with three replications. Fertilization sources were randomly assigned to the main plots, and the faba bean genotypes were allocated in sub-plots. Each plot had an area of 5.4 m², consisting of three ridges with each ridge measuring 3.0 m in length and 0.6 m in width. The faba bean genotypes were planted on November 5th and 9th in 2021, and 2022, respectively. The faba bean plants were grown in one row in 60 cm wide ridges with two plants per hill spaced 25 cm apart. Furrow irrigation was utilized

in the region, and all cultural practices for faba bean cultivation were carried out in accordance with recommended guidelines.

2.1. Fertilization Sources

2.1.1. Biological Fertilizer

It was carried out using one commercial product: Biogreen Power “Egyptian Algae Tech”. This fertilizer is made from pure algae. For foliar spraying, a concentration of 1 cm per liter is required, with 4.76 liters needed per hectare. The plants from each treatment were sprayed at 30 and 50 days after sowing. One bottle of Egyptian Algae Tech contains N “0.8%”, P₂O₅ “1.5%”, K₂O “1.5%”, CaO “0.4%”, MgO “0.25%”, S “0.8%”, Fe “1000 ppm”, Zn “1000 ppm”, Mn “500 ppm”, Cu “100 ppm”, B “100 ppm”, and Mo “250 ppm”.

2.1.2. Organic Fertilizer

It was carried out using one commercial product: compost tea. The plants from each treatment were sprayed at 30 and 50 days after sowing. One hectare requires 60 liters of compost, with a concentration of 20 liters of compost for every 100 liters of water. Compost was kindly provided by the Agricultural Microbiology Department of the ARC in Sakha, Kafr El-Sheikh governorate, Egypt, in order to make compost tea. It was made by brewing water and compost in a 1:10 w/v (compost: water) ratio under constant aeration for 48 hours. According to Naidu *et al.* [28], tap water was introduced to the brewing tank around 48 hours prior to usage to allow for volatilization and remove the presence of chlorine. Initially, during the brewing process, molasses (10 mL/L) with added as a carbon supplement to enhance the growth of beneficial microorganisms in the compost tea. The compost tea was then filtered after that. During the growth season, the compost tea characteristics were as follows: total count of bacteria (7.3 log cfu m/L), total count of actinomycetes (4.11 log cfu m/L), total count of fungi (4.01 log cfu m/L), pH (7.1), EC (2.40 dS/m), total N (5100 ppm), available P (3320 ppm) and available K (4156 ppm).

2.1.3. Mineral N Fertilizer

A commercial product containing 46% N (urea) was used as a mineral fertilizer. A total of 107.1 kg N/ha of mineral N fertilizer was applied in three equal doses: the first dose was applied before the first irrigation, the second dose before the second irrigation, and the third dose before the third irrigation.

2.2. The Studied Data

2.2.1. Foliar Diseases Assessment

Rust and chocolate spot incidence were assessed twice, at 70 and 90 days after sowing, on randomly selected plant genotypes using a 1 - 9 rating scale [29]. The rating scale is as follows:

1) Rust Resistance Levels

1. Highly resistant: no pustules or tiny, non-sporulating specks present.

3. Resistant: few or no pustules on the stem, with scattered pustules covering less than 1% of the leaf surface.

5. Moderately resistant: minimal defoliation, some pustules on the stem, and pustules on leaves accounting for 1% - 4% of the leaf area.

7. Susceptible: significant defoliation, numerous pustules on the stem, and pustules on leaves covering 4% - 8% of the leaf area.

9. Very susceptible: severe defoliation, many dead leaves, and large pustules on leaves, petioles, and stem, covering 8% - 10% of the leaf area.

2) Chocolate Spot Resistance Levels

1. No visible signs of the disease (highly resistant, 0% - 20%).

3. A small number of distinct, resistant lesions (2% - 15%).

5. Some lesions grouped together with moderate resistance (15% - 40%), leading to defoliation.

7. Susceptible plants (50% - 80%) show dead plant tissue, 50% defoliation, and large, clumped sporulating lesions.

9. Highly sensitive plants (80% - 100%) exhibit extensive lesions on leaves, stems, and pods, severe defoliation, profuse sporulation, stem girdling, blackening, and ultimately death.

The Hanounik [30] method was employed to assess the severity of rust and chocolate spot diseases.

$$\text{Disease severity (\%)} = \frac{\text{NPC} \times \text{CR}}{\text{NIP} \times \text{MSC}} \times 100$$

MSC represents the maximum severity class rate, NIP indicates the number of infected plants, CR is the class rate, and NPC denotes the number of plants in each class rate.

2.2.2. Seed Yield and Yield Components

At harvest, ten plants were chosen randomly from each plot to estimate the following traits: plant height (cm), number of branches per plant, number of pods per plant, and seed yield per plant (g). Seed yield per plot (kg) was recorded on the basis of the experimental plot and converted to ton per hectare.

2.2.3. Quality of Faba Bean Seeds

Quality of faba bean seeds was performed in laboratories of Seed Technology Research Department, Field Crops Research Institute, ARC. Samples of 50 grams from faba bean seeds were air dried, then ground and the fine powder stored in brown glass bottles. All the chemical determinations were estimated in ground seeds dried at 70°C till constant weight. The total N of faba bean seeds was determined using Microkjeldahl apparatus according to A.O.A.C. [31]. Crude protein content in faba bean seeds was calculated by multiplying total N by 6.25 [32]. Carbohydrate content in faba bean seeds was analyzed according to Duis *et al.* [33].

2.2.4. Farmers' Profits

Farmers' profits were used to compare costs and returns amongst different target

foliar diseases control treatments. Average of production costs of faba bean per hectare was recorded from Bulletin of Statistical Cost Production and Net Return [4]. Market price of faba bean was 330 USD/ton. It was estimated that land preparation, seeding & planting, irrigation, labor and crop field service treatment required 268.30 USD/ha. The cost of harvesting, transporting the crop and expenses were 154.65 USD/ha. The cost of renting the land was 261.65 USD/ha. Application of biological fertilization treatment required 16.66 USD/ha. While, application of organic fertilization treatment required 6.00 USD/ha. Mineral N fertilization treatment required 81.40 USD/ha. Net returns (USD/ha) were calculated by subtracting the cost of plant protection along with other costs (USD/ha) from the gross returns. Benefit Cost (B:C) ratio was obtained by taking the ratio of gross returns to the financial costs including the plant protection measures. B:C ratio = [gross returns (USD/ha)/financial costs (USD/ha)] × 100.

2.3. Statistical Analysis

Mean comparisons were conducted using the least significant differences (L.S.D) test at a significance level of 5% [34]. The measured variables were analyzed by ANOVA using the MSTATC statistical package [35].

3. Results and Discussion

3.1. Reaction to Foliar Diseases

3.1.1. Rust Disease Incidence

1) Fertilization Sources

The effect of different fertilization sources on rust disease incidence in faba bean plants was not significant after 70 and 90 days from sowing in both seasons (Table 3). This lack of significance may be attributed to the intricate interactions among nutrient availability, plant physiology, and environmental conditions [36].

Table 3. Effect of fertilization sources, faba bean genotypes and their interactions on leaf rust disease incidence after 70 and 90 days from sowing in both seasons.

Treatments	Rust Disease Incidence			
	70 days		90 days	
Giza 40	3.00	3.00	5.33	6.66
Giza 716	2.33	3.00	3.33	4.00
Sakha 1	1.00	1.66	2.66	3.00
Biological fertilization	2.00	2.00	3.33	3.00
L2039/437/2015	2.00	2.00	2.66	3.33
L2141/353/2015	2.00	2.00	2.66	4.33
L2103/591/2014	1.00	2.00	3.00	3.66
L2144/379/2015	2.00	2.00	2.00	3.66

Continued

	Mean	1.91	2.20	3.12	3.95
Organic fertilization	Giza 40	3.00	3.00	5.33	6.00
	Giza 716	2.00	3.00	2.66	4.00
	Sakha 1	2.33	2.00	3.33	4.00
	Sakha 4	1.00	1.00	2.66	3.00
	L2039/437/2015	2.00	2.00	3.33	4.00
	L2141/353/2015	1.33	2.00	2.33	3.33
	L2103/591/2014	2.00	2.00	3.33	4.00
	L2144/379/2015	1.66	2.00	2.00	3.66
	Mean	1.91	2.12	3.12	4.00
Mineral N fertilization	Giza 40	2.00	1.66	3.00	6.00
	Giza 716	2.00	3.00	2.00	3.66
	Sakha 1	2.00	3.00	3.33	4.00
	Sakha 4	2.00	2.00	2.66	4.00
	L2039/437/2015	1.00	2.00	2.66	3.00
	L2141/353/2015	2.00	2.00	3.66	4.66
	L2103/591/2014	2.00	2.00	3.00	4.33
	L2144/379/2015	2.00	2.00	4.00	4.33
	Mean	1.87	2.20	3.04	4.25
Average of faba bean genotypes	Giza 40	2.66	2.55	4.55	6.22
	Giza 716	2.11	3.00	2.66	3.88
	Sakha 1	1.77	2.22	3.11	3.66
	Sakha 4	1.66	1.66	2.88	3.33
	L2039/437/2015	1.66	2.00	2.88	3.44
	L2141/353/2015	1.77	2.00	2.88	4.11
	L2103/591/2014	1.66	2.00	3.11	4.00
	L2144/379/2015	1.88	2.00	2.66	3.88
LSD 5% Fertilization source	ns	ns	ns	ns	
LSD 5% Faba bean genotype	0.36	0.23	0.68	1.01	
LSD 5% Interaction	0.45	0.35	0.85	1.22	

2) Faba bean Genotypes

Faba bean genotypes showed significant differences in rust disease incidence after 70 and 90 days from sowing in both seasons (**Table 3**). Sakha 4, Sakha 1, Giza 716, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 exhibited higher resistance to rust disease compared to other genotypes, while Giza 40 was susceptible.

In the first season, Sakha 4, Sakha 1, Giza 716, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 had lower rust disease incidence by 37.59, 33.45, 20.67, 37.59, 33.45, 37.59, and 29.32% as compared to Giza 40 after 70 days from sowing. Similarly, after 90 days from sowing in the first season, these genotypes showed lower rust disease incidence by 36.70, 31.64, 41.53, 36.70, 36.70, 31.64, and 41.53%, respectively. In the second season, Sakha 4, Sakha 1, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 had lower rust disease incidence by 34.90, 12.94, 21.56, 21.56, 21.56, and 21.56%, respectively, as compared to Giza 40 after 70 days from sowing. After 90 days from sowing in the second season, Sakha 4, Sakha 1, Giza 716, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 exhibited lower rust disease incidence by 46.46, 41.15, 37.62, 44.69, 33.92, 35.69, and 37.62%, respectively. These results reveal that the resistance to rust disease in these particular genotypes may be attributed to genetic factors, indicating the potential for breeding programs to form faba bean varieties with increased resistance in the future [37]. These findings suggest that breeding programs could focus on incorporating the resistance traits found in Sakha 4, Sakha 1, Giza 716, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 to enhance overall rust disease resistance in faba bean crops. Certain genotypes consistently showed lower rust disease incidence in both seasons after 70 and 90 days from sowing, indicating their potential resistance to rust disease compared to other genotypes in the study. These findings align with previous studies by Amer *et al.* [38] and [39], El-Sayed *et al.* [40], Mohamed and El-Bakery [24], and Mostafa *et al.* [41], which also found that Giza 40 is susceptible to rust disease, while faba bean genotypes Sakha 4, Sakha 1, and Giza 716 exhibit resistance to the disease. These results are consistent with Soliman *et al.* [23], who found that specific genetic markers in faba beans are linked to resistance against rust disease.

3) The Interaction between Fertilization Sources and Faba bean Genotypes

The interaction between fertilization sources and faba bean genotypes significantly influenced rust disease incidence after 70 and 90 days from sowing in both seasons (**Table 3**). Sakha 4 treated with organic fertilization exhibited lower rust disease incidence compared to plants with mineral N or biological fertilization after 70 days of sowing in both seasons. However, by 90 days after sowing, there was no significant difference in rust incidence in Sakha 4 based on the fertilization source. The initial growth boost from organic fertilization may have contributed to early-stage resistance to rust disease. The long-term effects of fertilization sources on disease resistance in faba bean may vary depending on environmental

factors [14]. Sakha 1 treated with biological fertilization showed reduced rust disease incidence 70 days after sowing in both seasons compared to plants treated with mineral N or organic fertilization. However, there was no significant difference in rust incidence among Sakha 1 plants based on fertilization source 90 days after sowing. This suggests that algae may enhance early resistance to rust disease in plants, but this effect may diminish as the plant matures. Other factors such as genetic predisposition of the genotype and environmental conditions could also influence disease incidence. Variations in nutrient availability and defense mechanisms of faba bean genotypes are influenced by the fertilization source, which can affect their ability to resist rust disease incidence [14]. In the first season, Giza 716 treated with mineral N fertilization showed lower rust disease incidence compared to biological or organic fertilization 90 days after sowing. However, the fertilization source did not significantly affect the rust incidence of Giza 716 at 70 days after sowing in both seasons and at 90 days after sowing in the second season. These results may be attributed to the differences in nutrient uptake and utilization of Giza 716, which influenced its resistance to rust disease. At 70 and 90 days after sowing in both seasons, Giza 40 and L2039/437/2015 treated with mineral N fertilization had a lower incidence of rust disease than those treated with biological or organic fertilization. The study suggests that using mineral N fertilization may offer better protection against rust disease in Giza 40 and L2039/437/2015 compared to biological or organic fertilization. At 90 days after sowing in both seasons, there was no significant difference in rust incidence in L2103/591/2014 based on the fertilization source. These results suggest that L2103/591/2014 may have developed increased resistance to rust disease over time, independent of the fertilization source used. The initial advantages of biological fertilizer in reducing rust disease incidence may diminish as the plant strengthens its defense mechanisms. In comparison to L2141/353/2015 treated with biological or mineral N fertilization, L2141/353/2015 given organic fertilizer exhibited a decreased incidence of rust disease at 70 and 90 days from sowing in both seasons. These findings imply that L2141/353/2015 may be more resistant to rust disease when cultivated with organic fertilizer, maybe as a result of the soil's nutrients and microbial activity. In comparison to those treated with mineral N fertilization in both seasons, rust disease was less prevalent in L2144/379/2015 treated with biological or organic fertilization at 70 and 90 days after sowing. These results show that L2144/379/2015 may have increased resistance to rust disease when treated with biological or organic fertilization compared to mineral N fertilization.

3.1.2. Chocolate Spot Disease Incidence

1) Fertilization Sources

At 70 days after planting in both seasons, there was a significant effect of fertilization sources on the incidence of chocolate spot disease in faba bean plants, but not at 90 days (Table 4). In the first season, the incidence of chocolate spot disease decreased by 13.70% and 21.48% in faba bean plants that received biological and organic fertilization compared to those treated with mineral N fertilization at 70

days from sowing. Similarly, in the second season, faba bean plants nourished with organic and biological fertilization showed a 9.54% and 11.06% lower incidence of chocolate spot disease, respectively, compared to plants treated with mineral N fertilization at 70 days from sowing. Variations in disease resistance among faba bean plants may be attributed to the diverse effects of fertilization sources on soil microbial activity and nutrient availability. These findings suggest that algae may enhance plant resistance to chocolate spot disease by increasing lytic enzyme activity and phytoalexin synthesis [42]. Specifically, Ahmed *et al.* [43] found that microbial treatment significantly elevated phenols and flavonoids in faba bean plants, leading to reduced chocolate spot incidence compared to untreated plants. This indicates that biological fertilization showed improved defense mechanisms against chocolate spot disease, possibly due to the beneficial effects of microbial activity on plant secondary metabolites, but this effect may diminish as the plant matures. Combining ascobin, citrin, and potassium is the most effective way to increase total phenolic compounds and enhance faba bean resistance to chocolate spot infections [44]. This highlights the importance of potassium in strengthening plant defenses. Research has shown that compost tea, rich in potassium, boosts phenolic compounds in faba bean leaves, reducing the incidence of leaf diseases such as chocolate spot. This finding underscores the significance of K in mitigating chocolate spot in faba bean plants. There was no noticeable difference in the incidence of chocolate spot disease in faba bean plants 90 days after sowing in both seasons, regardless of the fertilization source used. These findings indicate that the choice of fertilization source may not have a significant impact on the susceptibility of faba bean plants to chocolate spot disease.

2) Faba bean Genotypes

Faba bean genotypes showed significant variations in chocolate spot disease incidence after 70 and 90 days from sowing in both seasons (Table 4). Sakha 4, Sakha 1, L2039/437/2015 and L2141/353/2015 demonstrated higher resistance to chocolate spot disease compared to other genotypes, while Giza 40, Giza 716, L3, and L4 were found to be susceptible. In the first season, Sakha 4, Sakha 1, L2039/437/2015 and L2141/353/2015 exhibited lower chocolate spot disease incidence by 23.82, 15.88, 19.85, and 19.85%, respectively, compared to Giza 40 after 70 days from sowing. Similarly, after 90 days from sowing in the first season, these genotypes showed reduced chocolate spot disease incidence by 32.43, 45.04, 37.61, and 32.43%, respectively.

In the second season, Sakha 4, Sakha 1, L2039/437/2015 and L2141/353/2015 displayed lower chocolate spot disease incidence by 29.66, 22.33, 22.33, and 29.66%, respectively, compared to Giza 40 after 70 days from sowing. After 90 days from sowing in the second season, these genotypes showed decreased chocolate spot disease incidence by 34.01, 25.00, 38.52, and 18.03%, respectively. These results indicate that Sakha 4, Sakha 1, L2039/437/2015 and L2141/353/2015 are promising genotypes with increased resistance to chocolate spot disease compared to Giza 40, particularly in the second season. According to Amer *et al.* [38] and

[39], El-Sayed *et al.* [40], Mohamed and El-Bakery [24], and Mostafa *et al.* [41], Sakha 4, Sakha 1, and Giza 716 are resistant to chocolate spot disease, while Giza 40 is susceptible to it. These findings are consistent with their findings.

Table 4. Effect of fertilization sources, faba bean genotypes and their interactions on leaf chocolate spot disease incidence after 70 and 90 days from sowing in both seasons.

Treatments		Chocolate Spot Disease Incidence			
		70 days		90 days	
Biological fertilization	Giza 40	3.00	3.00	2.66	4.33
	Giza 716	3.00	3.00	2.00	3.33
	Sakha 1	2.00	2.00	2.00	3.00
	Sakha 4	2.33	2.00	2.33	2.66
	L2039/437/2015	2.00	2.33	2.33	2.00
	L2141/353/2015	2.00	2.00	4.00	5.00
	L2103/591/2014	2.33	2.00	2.00	3.66
	L2144/379/2015	2.00	2.66	2.33	2.66
Mean		2.33	2.37	2.45	3.33
Organic fertilization	Giza 40	2.33	3.00	5.33	5.33
	Giza 716	2.00	2.66	3.00	3.66
	Sakha 1	2.00	2.33	2.33	3.66
	Sakha 4	2.00	2.00	3.66	4.00
	L2039/437/2015	2.00	2.00	3.00	3.66
	L2141/353/2015	2.33	2.33	2.00	2.66
	L2103/591/2014	2.00	2.33	3.66	5.00
	L2144/379/2015	2.33	2.00	3.33	4.00
Mean		2.12	2.33	3.28	4.00
Mineral N fertilization	Giza 40	3.00	3.00	5.33	5.00
	Giza 716	3.00	3.00	4.00	5.00
	Sakha 1	3.00	2.66	3.00	4.33
	Sakha 4	2.00	2.33	3.00	3.00
	L2039/437/2015	2.66	2.66	3.00	3.33
	L2141/353/2015	2.33	2.00	3.00	4.33
	L2103/591/2014	2.66	3.00	3.00	3.66
	L2144/379/2015	3.00	2.33	4.00	5.66

Continued

	Mean	2.70	2.62	3.54	4.28
	Giza 40	2.77	3.00	4.44	4.88
	Giza 716	2.66	2.88	3.00	4.00
	Sakha 1	2.33	2.33	2.44	3.66
	Sakha 4	2.11	2.11	3.00	3.22
Average of faba bean genotypes	L2039/437/2015	2.22	2.33	2.77	3.00
	L2141/353/2015	2.22	2.11	3.00	4.00
	L2103/591/2014	2.33	2.44	2.88	4.11
	L2144/379/2015	2.44	2.33	3.22	4.11
LSD 5% Fertilization source		0.19	0.19	ns	ns
LSD 5% Faba bean genotype		0.50	0.58	0.64	1.13
LSD 5% Interaction		0.63	ns	0.77	1.27

3) The Interaction between Fertilization Sources and Faba bean Genotypes

The incidence of chocolate spot disease was significantly affected by the interaction of fertilization sources and faba bean genotypes after 70 and 90 days from sowing in the first season and after 90 days from sowing in the second (Table 4). Sakha 4, Sakha 1, and Giza 716 treated with biological fertilization showed a lower incidence of chocolate spot disease compared to plants fed with biological or mineral fertilization, particularly after 90 days from sowing in both seasons. This suggests that biological fertilization may have a positive impact on disease resistance in Sakha 4, Sakha 1, and Giza 716 potentially leading to higher yields. The incidence of chocolate spot disease was lower in Giza 40 and L2039/437/2015 treated with biological fertilization than in those treated with organic or mineral N fertilization after 90 days of sowing in both seasons. This suggests that biological fertilization may be more effective in reducing the incidence of chocolate spot disease in Giza 40 and L2039/437/2015 compared to organic or mineral N fertilization. Compared to L2141/353/2015 treated with biological or mineral N fertilization, L2141/353/2015 treated with organic fertilizer showed a reduced incidence of chocolate spot disease at 90 days after sowing in both seasons. These results suggest that L2141/353/2015 may exhibit increased resistance to chocolate spot disease when grown with organic fertilizer, possibly due to enhanced soil nutrients and microbial activity. At 70 and 90 days after planting, L2103/591/2014 and L2144/379/2015 treated with biological fertilization showed resistance to chocolate spot disease compared to those treated with organic or mineral N fertilization in both seasons. According to these findings, L2103/591/2014 and L2144/379/2015 reacted well to biological fertilization, suggesting that L2103/591/2014 and L2144/379/2015 may be more resistant to chocolate spot diseases.

3.2. Seed Yield and Yield Components

3.2.1. Fertilization Sources

Plant height, number of pods per plant, seed yield per plant, and seed yield per hectare were significantly affected by fertilization sources in both seasons (**Table 5**). When compared to organic fertilization in the first season, biological fertilization significantly improved plant height, number of pods per plant, seed yield per plant, and seed yield per hectare by 1.75%, 19.69%, 17.80%, and 26.27%, respectively. When compared to organic fertilization, biological fertilization significantly increased plant height, number of pods per plant, seed yield per plant, and seed yield per hectare in the second season by 5.45%, 5.04%, 7.44%, and 7.03%, respectively. In addition, compared to mineral N fertilization, biological fertilizer significantly increased plant height, number of pods per plant, seed yield per plant, and seed yield per hectare in the first season by 7.17%, 11.48%, 11.93%, and 18.63%, respectively. In the second season, biological fertilization led to a significant increase in plant height, number of pods per plant, seed yield per plant, and seed yield per hectare by 4.42%, 1.79%, 4.87%, and 6.77%, respectively, compared to mineral N fertilization. These results indicate that biological fertilization can have a positive impact on plant growth and yield compared to mineral N fertilization. Biological fertilization has positive outcomes as it provides plants with essential elements for optimal growth and development. These results can be attributed to the varying nutritional benefits offered by each type of fertilizer, as well as differences in nutrient absorption efficiency between mineral and biological fertilizers [45]. Additionally, fertilizers stimulate microbial activity, enhancing nutrient uptake and plant growth [46]. These findings suggest that biological fertilization may be more beneficial for promoting plant growth and seed production compared to organic and mineral N treatments, indicating its potential as a viable alternative for boosting crop productivity and sustainability. It is evident from this study that the seed yield of faba beans and yield components was affected similarly by organic fertilization and mineral N fertilization. This might be because both types of fertilizers provide essential nutrients for plant growth and development, leading to similar effects on seed yield and yield components. Additionally, the similar effects could also be attributed to the fact that both organic and mineral N fertilizers improve soil health and fertility, forming optimal conditions for plant growth. These findings are consistent with Mohamed *et al.* [47], who reported that foliar application of amino acid compounds on faba bean plants significantly increased seed yield and yield attributes. Similarly, Cucci *et al.* [48] found that incorporating 140 mg per hectare of wet olive pomace with half the usual N, P, and K mineral fertilization dose could yield the same amount of faba beans as full mineral fertilization.

The use of organic manure led to significant improvements in faba bean yield characteristics, such as the number of pods per plant, pod length, weight of 100 seeds, and total yield [49]. These results suggest that organic fertilization could potentially reduce the reliance on mineral fertilizers in faba bean production, offering environmental benefits and cost savings.

Table 5. Effect of fertilization sources, faba bean genotypes and their interactions on seed yield and yield components in both seasons.

Treatments	Plant height (cm)		Number of branches/plant		
	First season	Second season	First season	Second season	
Biological fertilization	Giza 40	120.00	115.00	2.75	2.75
	Giza 716	113.33	108.33	3.16	3.33
	Sakha 1	123.33	98.33	3.41	3.66
	Sakha 4	110.00	100.33	3.50	4.00
	L2039/437/2015	123.33	101.66	2.75	3.66
	L2141/353/2015	133.33	136.66	2.96	3.33
	L2103/591/2014	120.00	117.66	3.33	3.33
	L2144/379/2015	117.66	116.66	3.33	3.66
Mean	120.62	111.82	3.14	3.46	
Organic fertilization	Giza 40	120.00	115.00	2.93	2.96
	Giza 716	126.66	101.66	3.00	3.00
	Sakha 1	123.33	108.33	3.13	4.00
	Sakha 4	108.33	108.33	3.50	3.66
	L2039/437/2015	113.33	95.00	3.00	3.00
	L2141/353/2015	123.33	98.33	3.40	3.33
	L2103/591/2014	116.66	98.33	3.00	3.66
	L2144/379/2015	116.66	123.33	3.00	3.33
Mean	118.54	106.04	3.12	3.36	
Mineral N fertilization	Giza 40	123.33	101.66	3.00	3.33
	Giza 716	110.00	108.33	3.33	3.66
	Sakha 1	96.66	95.00	3.33	3.00
	Sakha 4	101.66	110.00	3.33	3.66
	L2039/437/2015	117.66	111.66	3.33	3.66
	L2141/353/2015	116.66	123.33	3.00	3.66
	L2103/591/2014	117.66	100.00	3.33	3.66
	L2144/379/2015	116.66	106.66	3.33	3.00
Mean	112.54	107.08	3.24	3.45	
Average of faba bean genotypes	Giza 40	121.11	110.55	2.89	3.01
	Giza 716	116.66	106.11	3.16	3.33
	Sakha 1	114.44	100.55	3.29	3.55
	Sakha 4	106.66	106.22	3.44	3.77
	L2039/437/2015	118.11	102.77	3.02	3.44
	L2141/353/2015	124.44	119.44	3.12	3.44
	L2103/591/2014	118.11	105.33	3.22	3.55
	L2144/379/2015	117.00	115.55	3.22	3.33
LSD 5% Fertilization source	6.46	4.26	ns	ns	
LSD 5% Faba bean genotype	8.32	6.34	ns	ns	
LSD 5% Interaction	11.75	8.67	ns	ns	

Continued

Treatments	Number of pods/plant		Seed yield/plant (g)		Seed yield/ha (ton)		
	First season	Second season	First season	Second season	First season	Second season	
Biological fertilization	Giza 40	12.16	11.21	32.36	24.10	3.33	2.96
	Giza 716	17.19	15.33	41.20	35.73	5.44	4.44
	Sakha 1	18.25	19.36	44.10	43.33	5.60	5.54
	Sakha 4	18.83	20.33	48.16	48.36	5.77	5.82
	L2039/437/2015	13.61	15.83	32.90	38.43	3.58	4.53
	L2141/353/2015	15.75	14.80	35.56	33.36	4.18	3.24
	L2103/591/2014	17.75	15.40	37.80	34.70	4.72	3.82
	L2144/379/2015	17.75	19.33	38.70	41.20	5.09	4.97
Mean	16.41	16.44	38.84	37.40	4.71	4.41	
Organic fertilization	Giza 40	9.33	10.33	22.06	21.33	2.29	2.13
	Giza 716	11.40	15.66	31.59	35.40	3.20	4.43
	Sakha 1	16.56	19.33	36.36	41.56	4.38	5.08
	Sakha 4	16.60	19.36	38.43	42.46	4.77	5.43
	L2039/437/2015	14.00	11.30	34.11	24.47	3.96	2.73
	L2141/353/2015	16.80	15.16	36.25	35.50	4.30	3.93
	L2103/591/2014	13.00	19.10	33.05	41.80	3.64	5.28
	L2144/379/2015	12.04	14.96	31.94	35.96	3.30	3.97
Mean	13.71	15.65	32.97	34.81	3.73	4.12	
Mineral N fertilization	Giza 40	12.79	15.21	32.25	35.42	3.12	3.90
	Giza 716	15.69	18.30	35.92	40.83	4.31	4.89
	Sakha 1	16.41	11.56	36.89	24.10	4.52	2.79
	Sakha 4	14.68	18.16	34.90	40.33	4.02	4.78
	L2039/437/2015	16.20	17.00	36.47	39.92	4.40	4.66
	L2141/353/2015	13.13	18.76	32.67	40.96	3.42	4.79
	L2103/591/2014	13.52	19.16	33.34	40.13	3.85	4.60
	L2144/379/2015	15.35	11.06	35.21	23.66	4.17	2.63
Mean	14.72	16.15	34.70	35.66	3.97	4.13	
Average of faba bean genotypes	Giza 40	11.42	12.25	28.89	26.95	2.91	2.99
	Giza 716	14.76	16.43	36.23	37.32	4.31	4.58
	Sakha 1	17.07	16.75	39.11	36.33	4.83	4.47
	Sakha 4	16.70	19.28	40.49	43.71	4.85	5.34
	L2039/437/2015	14.60	14.71	34.49	34.27	3.98	3.97
	L2141/353/2015	15.22	16.24	34.82	36.60	3.96	3.98
	L2103/591/2014	14.75	17.88	34.73	38.87	4.07	4.56
	L2144/379/2015	15.04	15.11	35.28	33.60	4.18	3.85
LSD 5% Fertilization source	1.48	0.27	5.67	1.59	0.61	0.26	
LSD 5% Faba bean genotype	1.12	0.22	4.02	1.26	0.30	0.17	
LSD 5% Interaction	1.69	0.32	6.88	1.68	0.77	0.41	

3.2.2. Faba bean Genotypes

Faba bean genotypes showed significant differences in plant height, pod number per plant, seed yield per plant and seed yield per hectare across the two seasons (**Table 5**). In the first season, Giza 40, Giza 716, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 displayed taller plant heights (121.11, 116.66, 118.11, 124.44, 118.11, and 117 cm, respectively) compared to other genotypes. In the second season, L2141/353/2015 and L2144/379/2015 exhibited taller plant heights (119.44 and 115.55 cm, respectively) compared to other genotypes. For the number of pods per plant, Sakha 4 and Sakha 1 had higher values (16.70 and 17.07, respectively) compared to other genotypes in the first season. In the second season, Sakha 4 had a higher number of pods per plant (19.28) compared to other genotypes. In terms of seed yield per plant, Sakha 4 and Sakha 1 had higher yields (40.49 and 39.11 g, respectively) compared to other genotypes. In the second season, Sakha 4 had the highest seed yield per plant (43.71 g) compared to other genotypes. For seed yield per hectare, Sakha 4 and Sakha 1 had higher values (4.85 and 4.83 tons, respectively) compared to other genotypes in the first season. In the second season, Sakha 4 had the highest seed yield per hectare (5.34 tons) compared to other genotypes. These results were attributed to the resistance of Sakha 4 and Sakha 1 to foliar diseases (**Table 3** and **Table 4**), enabling them to maintain high productivity levels throughout both seasons. Additionally, the genetic characteristics of Sakha 4 contributed to its superior performance in terms of seed yield per plant and per hectare, highlighting its potential for increased productivity in faba bean cultivation. Meanwhile, Sakha 1 also demonstrated promising results in terms of seed yield per hectare, making it another viable option for farmers seeking to maximize their yield. Sakha 3 and Sakha 4 exhibited higher levels of photosynthetic pigments compared to other cultivars, potentially accounting for these findings [50]. These results indicate that Sakha 4 and Sakha 1 consistently showed higher productivity compared to the other genotypes in both seasons, making them the top performers in terms of seed production. Overall, the data suggests that Sakha 4 and Sakha 1 are the most reliable genotypes for achieving high seed yields consistently across different seasons. This information can be valuable for farmers looking to maximize their seed production. These findings align with Amer *et al.* [38], who showed that Sakha 4 yielded 15.5% and 24.1% more than Sakha 1 and Sakha 3, respectively. Furthermore, Mohamed *et al.* [47] found that Sakha 1 had higher seed yield and yield attributes compared to Masr 3. Similarly, Akgun and Canci [51] observed significant differences in plant height, number of pods per plant, and seed yield. The resistance to foliar diseases (**Table 3** and **Table 4**) in faba bean genotypes Giza 716, L2039/437/2015, L2141/353/2015, L2103/591/2014, and L2144/379/2015 resulted in increased plant height, pod number per plant, seed yield per plant, and seed yield per hectare. These traits also positively influenced dry matter accumulation during growth and development, enhancing overall plant growth, vigor, and performance throughout the season. The disease-resistant characteristics of Giza 716 significantly con-

tributed to their productivity [40]. Conversely, the susceptibility of faba bean genotype Giza 40 to foliar diseases significantly impacted seed production and yield components. The reduced output was attributed to Giza 40's susceptibility to diseases, as reported by El-Sayed *et al.* [40].

3.2.3. The Interaction between Fertilization Sources and Faba Bean Genotypes

The interaction between fertilization sources and faba bean genotypes affected significantly plant height, pod number per plant, seed yield per plant, and seed yield per hectare in the two seasons (Table 5). L2141/353/2015, treated with biological fertilization, showed increased plant height in both seasons. In contrast, Sakha 1, treated with mineral N fertilization, exhibited lower plant height values compared to other treatments. These results indicate that L2141/353/2015 positively responded to biological fertilization, leading to enhanced plant height, while Sakha 1 did not show the same response to mineral N fertilization. Regarding pod production and seed yield, Sakha 4, Sakha 1, Giza 716, and L2144/379/2015 treated with biological fertilization demonstrated higher number of pods per plant, seed yield per plant, and seed yield per hectare compared to organic or mineral N fertilization in both seasons. This improvement can be attributed to the enhanced nutrient availability and improved soil health resulting from biological fertilization [52]. This suggests that these genotypes responded favorably to biological fertilization, potentially increasing productivity with this treatment. Additionally, Sakha 4, Sakha 1, and Giza 716 showed resistance to chocolate spot diseases when treated with biological fertilization (Table 4), indicating improved disease resistance in these genotypes. On the other hand, L2144/379/2015 exhibited resistance to foliar diseases when treated with biological fertilization (Table 3 and Table 4), highlighting the potential of this source to protect against diseases in certain genotypes. In contrast, Giza 40 and L2039/437/2015 exhibited higher pod numbers and seed yields when mineral N fertilization was used, as opposed to biological or organic fertilization. This was due to the increased availability of nutrients for plant uptake, leading to enhanced growth and productivity. These results indicate a preference for mineral N fertilization for these genotypes. Giza 40 and L2039/437/2015 also exhibited less susceptible to foliar diseases when treated with mineral N fertilization (Table 3 and Table 4) compared to biological or organic fertilization. Furthermore, plants of genotype L2141/353/2015 treated with organic fertilization exhibited higher pod numbers and seed yields. This was attributed to increased nutrient availability and improved soil health compared to biological or mineral N fertilization in the first season. Additionally, these plants showed resistance to foliar diseases when treated with organic fertilization. In the second season, plants of genotype L2141/353/2015 treated with mineral N fertilization exhibited higher pod numbers and seed yields compared to those treated with biological or organic fertilization. However, these plants were more susceptible to foliar diseases due to the higher N content in the mineral fertilizer. In the first season, L2103/591/2014 yielded more seeds with biological fertilization, while

in the second season, L2103/591/2014 showed higher seed yield with organic fertilization. The increased resistance to foliar diseases in the first season, attributed to biological fertilization (Table 3 and Table 4), likely contributed to these results. Conversely, in the second season, environmental factors, such as climate, may have enhanced L2103/591/2014 resistance to foliar diseases through organic fertilization. The performance of L2103/591/2014 appears to be influenced by both biological and organic fertilization methods, as well as external factors like climate.

3.3. Quality of Faba Bean Seeds

3.3.1. Fertilization Sources

Seed protein and carbohydrates contents were significantly affected by fertilization sources in both seasons (Table 6). In both seasons, seed fertilization with biological or organic fertilizers resulted in higher levels of seed protein and carbohydrates contents compared to mineral N fertilization. This difference may be attributed to the presence of additional nutrients and beneficial microorganisms in biological fertilizers, which enhance nutrient uptake and plant growth. Similar results were obtained by Osman *et al.* [53] and Alhammad and Seleiman [52], who showed that bio-fertilization improved seed quality by increasing N, P, protein, and carbohydrate contents, support these findings. With respect to organic fertilization, organic fertilization improved nutrient availability and plant absorption, leading to increased protein and carbohydrate contents in seeds compared to mineral N fertilization. El-Gizawy and Mehasen [54] found that adding 30 kg P₂O₅ along with phosphate-dissolving bacteria significantly increased seed protein percentage, supporting the benefits of organic fertilization.

Table 6. Effect of fertilization sources, faba bean genotypes and their interactions on seed protein and carbohydrates contents in both seasons.

Treatments	Seed protein content (%)		Seed carbohydrates content (%)	
	First season	Second season	First season	Second season
Giza 40	23.40	23.19	53.39	53.26
Giza 716	23.51	23.25	54.02	54.36
Sakha 1	24.80	24.45	57.64	55.59
Biological fertilization				
Sakha 4	23.36	24.17	53.94	55.04
L2039/437/2015	23.18	21.12	53.73	54.43
L2141/353/2015	25.09	25.76	55.82	55.14
L2103/591/2014	24.37	25.08	54.94	54.23
L2144/379/2015	22.82	22.83	53.63	53.38

Continued

	Mean	23.81	23.73	54.63	54.42
Organic fertilization	Giza 40	23.38	23.04	53.43	53.33
	Giza 716	24.88	24.62	55.46	54.91
	Sakha 1	26.19	25.93	59.10	56.95
	Sakha 4	25.85	25.42	55.24	55.92
	L2039/437/2015	24.52	23.51	55.10	55.58
	L2141/353/2015	23.70	24.48	54.17	53.89
	L2103/591/2014	23.03	23.79	53.67	53.45
	L2144/379/2015	23.96	23.20	55.01	54.06
	Mean	24.43	24.24	55.14	54.76
Mineral N fertilization	Giza 40	20.54	19.72	50.97	50.79
	Giza 716	21.47	20.63	51.20	50.34
	Sakha 1	21.16	20.42	55.00	50.61
	Sakha 4	20.17	20.29	50.17	50.93
	L2039/437/2015	20.51	20.20	50.61	49.90
	L2141/353/2015	21.69	20.34	52.65	50.75
	L2103/591/2014	20.41	20.44	51.73	50.82
	L2144/379/2015	20.54	19.70	51.87	49.11
	Mean	20.81	20.21	51.77	50.40
Average of faba bean genotypes	Giza 40	22.44	21.98	52.59	52.46
	Giza 716	23.28	22.83	53.56	53.20
	Sakha 1	24.05	23.60	57.24	54.38
	Sakha 4	23.12	23.29	53.11	53.96
	L2039/437/2015	22.73	21.61	53.14	53.30
	L2141/353/2015	23.49	23.52	54.21	53.26
	L2103/591/2014	22.60	23.10	53.44	52.83
	L2144/379/2015	22.44	21.91	53.50	52.18
LSD 5% Fertilization source	1.27	1.13	1.08	0.93	
LSD 5% Faba bean genotype	1.03	0.81	0.87	0.78	
LSD 5% Interaction	1.46	1.37	1.29	1.18	

3.3.2. Faba bean Genotypes

Significant variations in seed quality were observed between the two seasons for the faba bean genotypes (**Table 6**). In the first season, Sakha 1, Sakha 4, Giza 716, and L2141/353/2015 had higher seed protein content compared to other genotypes (24.05%, 23.12%, 23.28%, and 23.49%, respectively). Conversely, in the second season, Sakha 1, Sakha 4, L2141/353/2015, and L2103/591/2014 had higher seed protein content than the other genotypes (23.60%, 23.29%, 23.52%, and 23.10%, respectively). Sakha 1, Sakha 4, and L2141/353/2015 consistently showed increased seed protein content in both seasons, indicating their potential for future breeding efforts to improve seed quality. The variation in seed quality among genotypes underscores the importance of selecting appropriate cultivars based on specific growing conditions and intended end-use applications. Among the genotypes, Sakha 1 and L2141/353/2015 exhibited higher seed carbohydrate contents (57.24% and 54.21%, respectively) compared to others. Similarly, in the second season, Sakha 1, Sakha 4, Giza 716, L2039/437/2015, and L2141/353/2015 had higher seed carbohydrate content than the rest (54.38%, 53.96%, 53.20%, 53.30%, and 53.26%, respectively). Sakha 1 and L2141/353/2015 are promising choices for those seeking faba beans with higher seed carbohydrate content. Farmers and researchers should consider these differences in seed quality when selecting the most suitable genotypes for their specific needs. Mohamed *et al.* (2018) found that the faba bean cultivar Sakha 1 had better seed quality than Masr 3, which is consistent with these findings. Faba bean genotype Elisar had the highest protein content, while the faba bean genotype FLIP03-005FB had the lowest [51].

3.3.3. The Interaction between Fertilization Sources and Faba Bean Genotypes

The interaction between fertilization sources and faba bean genotypes affected significantly seed quality in the two seasons (**Table 6**). Sakha 1, Sakha 4, L2039/437/2015, and L2144/379/2015 exhibited higher seed protein and carbohydrate contents when treated with organic fertilization compared to other treatments in both seasons. This can be attributed to the organic fertilizers' ability to supply essential nutrients in a balanced and easily accessible form for the plants, enhancing plant growth and nutrient absorption, resulting in increased protein and carbohydrate accumulation in the seeds [46]. This indicates that organic fertilization positively affects the nutritional composition of these genotypes, potentially improving seed quality. Similarly, L2103/591/2014 and L2141/353/2015 exhibited higher seed protein and carbohydrates contents when treated with biological fertilization, suggesting a positive impact on their nutritional composition and seed quality. Additionally, Giza 40 showed increased seed protein and carbohydrates contents when treated with biological or organic fertilization, indicating potential benefits for seed quality enhancement. In contrast, all tested faba bean genotypes treated with mineral N fertilization had lower seed protein and carbohydrate contents compared to those treated with organic or biological fertilization in both seasons. This difference may be attributed to variations in nutrient availability and

uptake efficiency between the fertilization methods [55]. This suggests that mineral N fertilization may not be as effective in improving the nutritional composition of faba bean seeds compared to organic or biological fertilization.

3.4. Farmer's Profits

The study evaluated faba bean genotypes for resistance to rust and chocolate spot diseases under various fertilization methods (biological, organic, and mineral N). Gross and net returns, as well as the B:C ratios, varied among treatments (Table 7). In the first season, gross returns ranged from 755.7 USD per hectare for Giza 40 with organic fertilization to 1904.1 USD per hectare for Sakha 4 with biological fertilization. In the second season, these values ranged from 702.9 USD per hectare to 1920.6 USD per hectare. The study showed that biological fertilization with Sakha 4 resulted in higher gross returns compared to organic fertilization, with an increase of 20.96% in the first season and 7.18% in the second season. Similarly, Sakha 1, paired with biological fertilization, showed an increase in gross returns by 27.85% in the first season and 9.05% in the second season compared to organic fertilization. In contrast, comparing biological fertilization with mineral N fertilization, Sakha 4 exhibited higher gross returns of 43.53% in the first season and 21.75% in the second season. On the other hand, Sakha 1 with biological fertilization had an increase in gross returns by 23.89% in the first season and a significant 98.56% in the second season compared to mineral N fertilization. These results highlight the potential of biological fertilization in enhancing the gross returns of faba bean crops, particularly when compared to organic or mineral N fertilization. The findings emphasize the importance of selecting the appropriate fertilization methods to optimize crop yield and profitability. Net returns varied from 65.1 USD per hectare for Giza 40 with organic fertilization to 1202.9 USD per hectare for Sakha 4 with biological fertilization in the first season. In the second season, net returns ranged from 12.3 USD per hectare to 1219.4 USD per hectare. B:C ratios ranged from 109.42 for Giza 40 with organic fertilization to 271.54 for Sakha 4 with biological fertilization in the first season. In the second season, these values ranged from 101.78 to 273.90. Giza 40 showed the lowest net returns and B:C ratios when fertilized with organic fertilization, while Sakha 4 had the highest returns and B:C ratios when fertilized with biological fertilization. Sakha 4 clearly produced the best monetary return, with Sakha 1 coming in second. This can be due to Sakha 1 and Sakha 4 becoming more resistant to the chocolate spot disease as a result of biological fertilization (Table 4), thereby increasing revenues.

These findings underscore the significant impact of fertilizer type on the economic outcomes of different faba bean genotypes. When using biological fertilizer instead of organic or mineral N fertilizers, Giza 716 demonstrated the best economic returns. This is probably because, when treated with biological fertilizer rather than organic or mineral N fertilizer, Giza 716 is resistant to chocolate spot disease (Table 4). According to the results, biological fertilization could be a better option for Giza 716's profit maximization. Giza 40 and L2039/437/2015 demonstrated

Table 7. Farmer's profits of the interaction between fertilization sources and faba bean genotypes in both seasons.

Treatments		Gross returns (USD/ha)		Financial costs (USD/ha)	
		First season	Second season	First season	Second season
Biological fertilization	Giza 40	1098.9	976.8	701.2	701.2
	Giza 716	1795.2	1465.2	701.2	701.2
	Sakha 1	1848.0	1828.2	701.2	701.2
	Sakha 4	1904.1	1920.6	701.2	701.2
	L2039/437/2015	1181.4	1494.9	701.2	701.2
	L2141/353/2015	1379.4	1069.2	701.2	701.2
	L2103/591/2014	1557.6	1260.6	701.2	701.2
	L2144/379/2015	1679.7	1640.1	701.2	701.2
Organic fertilization	Giza 40	755.7	702.9	690.6	690.6
	Giza 716	1056.0	1461.9	690.6	690.6
	Sakha 1	1445.4	1676.4	690.6	690.6
	Sakha 4	1574.1	1791.9	690.6	690.6
	L2039/437/2015	1306.8	900.9	690.6	690.6
	L2141/353/2015	1419.0	1296.9	690.6	690.6
	L2103/591/2014	1201.2	1742.4	690.6	690.6
	L2144/379/2015	1089.0	1310.1	690.6	690.6
Mineral N fertilization	Giza 40	1029.6	1287.0	766.0	766.0
	Giza 716	1422.3	1613.7	766.0	766.0
	Sakha 1	1491.6	920.7	766.0	766.0
	Sakha 4	1326.6	1577.4	766.0	766.0
	L2039/437/2015	1452.0	1537.8	766.0	766.0
	L2141/353/2015	1128.6	1580.7	766.0	766.0
	L2103/591/2014	1270.5	1518.0	766.0	766.0
	L2144/379/2015	1376.1	867.9	766.0	766.0

Continued

Treatments	Net returns (USD/ha)		B:C ratio		
	First season	Second season	First season	Second season	
Biological fertilization	Giza 40	397.7	275.6	156.71	139.30
	Giza 716	1094.0	764.0	256.01	208.95
	Sakha 1	1146.8	1127.0	263.54	260.72
	Sakha 4	1202.9	1219.4	271.54	273.90
	L2039/437/2015	480.2	793.7	168.48	213.19
	L2141/353/2015	678.2	368.0	196.71	152.48
	L2103/591/2014	856.4	559.4	222.13	179.77
	L2144/379/2015	978.5	938.9	239.54	233.89
Organic fertilization	Giza 40	65.1	12.3	109.42	101.78
	Giza 716	365.4	771.3	152.91	211.68
	Sakha 1	754.8	985.8	209.29	242.74
	Sakha 4	883.5	1101.3	227.93	259.47
	L2039/437/2015	616.2	210.3	189.22	130.45
	L2141/353/2015	728.4	606.3	205.47	187.79
	L2103/591/2014	510.6	1051.8	173.93	252.30
	L2144/379/2015	398.4	619.5	157.68	189.70
Mineral N fertilization	Giza 40	263.6	521.0	134.41	168.01
	Giza 716	656.3	847.7	185.67	210.66
	Sakha 1	725.6	154.7	194.72	120.19
	Sakha 4	560.6	811.4	173.18	205.92
	L2039/437/2015	686.0	771.8	189.55	200.75
	L2141/353/2015	362.6	814.7	147.33	206.35
	L2103/591/2014	504.5	752.0	165.86	198.17
	L2144/379/2015	610.1	101.9	179.64	113.30

Market price of faba bean was 330 USD/ton.

higher economic returns when mineral N fertilizer was used instead of biological or organic fertilizers. This could be attributed to their increased sensitivity to rust disease when biological or organic fertilizers were applied (**Table 3**), despite being less susceptible to chocolate spot disease under biological fertilization (**Table 4**). These results indicate that applying mineral N fertilizer to Giza 40 and L2039/437/2015 could decrease their susceptibility to rust disease, ultimately enhancing their economic returns. Regardless of the fertilization source, Giza 40 and L2039/437/2015 exhibited greater susceptibility to chocolate spot disease. The findings indicate that mineral N fertilization may be more beneficial for maximizing profits in Giza 40 and L2039/437/2015. When supplied with organic fertilizer, L2141/353/2015 yielded higher economic returns compared to those treated with biological or mineral fertilizers. The resistance of L2141/353/2015 to rust and chocolate spot diseases under organic fertilization (**Table 3** and **Table 4**) likely contributed to these results. The study suggests that organic fertilization can boost the economic viability of faba bean genotypes such as L2141/353/2015 by enhancing their resistance to foliar diseases, ultimately increasing profits for farmers. Biological fertilization of L2103/591/2014 resulted in a higher economic return in the first season, while organic fertilization led to a greater economic return in the second season. This difference may be attributed to the genotype's resistance to foliar diseases in the first season (**Table 3** and **Table 4**), making biological fertilization more beneficial. However, in the second season, organic fertilization may enhance resistance to L2103/591/2014 due to favorable climatic conditions. The choice between biological and organic fertilization for L2103/591/2014 should be based on specific goals and challenges in each growing season. Considering both options can optimize economic returns and seed yield in the long run. Compared to organic or mineral N fertilizers, L2144/379/2015 showed higher economic returns when treated with biological fertilizer. The genotype's resistance to foliar diseases under biological fertilizer may account for these results (**Table 3** and **Table 4**). These findings suggest that biological fertilization could be a cost-effective and eco-friendly approach to cultivating faba beans, especially for disease-resistant genotypes like L2144/379/2015.

4. Conclusion

This study could conclude that the choice of fertilization source should consider factors such as faba bean genotype, soil conditions, and desired yield outcomes. The faba bean genotypes Sakha 1, Sakha 4, Giza 716, and L2144/379/2015 exhibit increased resistance to chocolate spot disease due to biological fertilization, leading to higher productivity and profits. Giza 40 and L2039/437/2015 show higher productivity and economic returns when mineral N fertilizer is used, as organic fertilizers make plants more susceptible to rust disease. Sakha 1, Sakha 4, L2039/437/2015, and L2144/379/2015 had higher seed protein and carbohydrate contents with organic fertilization, while L2103/591/2014 and L2141/353/2015 had higher contents with biological fertilization. Giza 40 had increased contents with biolog-

ical or organic fertilization. L2144/379/2015 shows promise in foliar disease breeding programs due to its resistance to common diseases like rust and chocolate spot. This makes it a valuable candidate for enhancing crop yield and quality.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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