ISSN: 2637-7721

MEDDOCS Open Access Publisher

Journal of Plant Biology and Crop Research

Open Access | Research Article

The Role of Fences in Growth, Productivity, and Pest Control of Some Quinoa Genotypes to Enhance Stress Tolerance under Aeolian Deposit Conditions

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Received: Aug 01, 2023

Accepted: Aug 25, 2023

Published Online: Aug 31, 2023

Journal: Journal of Plant Biology and Crop Research

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/

Keywords: Artificial fences; Aeolian deposits; Microclimate; Chenopodium quinoa; Vegetative growth; Yield; Cotton leafworm; Aphid.

Abstract

Our study was carried out in Ismailia Governorate (Cairo Ismailia Desert Road) during two successive growing seasons (2020/2021 and 2021/2022) to evaluate the role of artificial fences under local climate in farming area affected by aeolian deposits and the effect of using fences on quinoa (Chenopodium quinoa Willd.) growth, productivity, and pest resistance under field conditions. The results obtained revealed that fences significantly decreased average wind speed in the study area by 34.17% and 37.37%, respectively, in the two seasons. Meanwhile, soil temperature increased significantly by 2.2-2.5 °C, which led to an increase in the percentage of germination, plant length, leaf area, and yield of all tested quinoa genotypes. In addition, this helped to diminish the incidence of cotton leafworm and aphid infestations. Based on our results, the use of *theran* and reed fences could be recognized as an important agricultural practice that can improve seed germination, productivity, and the yield and pest control of quinoa plants under aeolian deposit conditions.

Introduction

The world is facing alarming challenges due to climate change and variability as illustrated by various climatic models [1] It is projected to have a temperature increase of 2-4°C in the 21st century, and more than 4°C by the end of the century. Climate change models project a hotter, drier and more diverse environment, leading to a 20-30% reduction in runoff across most of the region by 2050.

As the climate continues to heat up and its impacts grow more frequent and severe, agriculture production will be more challenging and rural communities around the world will be increasingly challenged. Climate change impacts are reflected not only on the water availability for agriculture, but as well on the crop losses due to emergence of new pests and diseases for major food and cash crops. Crop losses are a major threat to the wellbeing of rural families, to local and national economy and stability, and to food security worldwide [2].

The Mediterranean and North Africa are among the regions' most vulnerable to the impact of climate change. With summer temperatures rising and rainfall diminishing, as these temperatures rise, the crisis becomes more apparent. Global warming could lead to an increase in insect pest numbers, which will harm crop yields. Although warmer temperatures cause longer growing seasons and faster growth rates for plants, they also increase the metabolic rate and number of reproductive cycles in insects.

Ismailia Governorate is positioned on a low site that has elevations above sea level, ranging from 1 up to 33 m [3].

One way to reduce the impact of climate change is to use windbreaks, shelterbelts, and artificial fences [4-7]. Therefore, we resort to some interventions that mitigate the severity of climate change, such as the use of windbreaks and industrial fences.

Quinoa (*Chenopodium quinoa*) is an herbaceous annual crop belonging to the family Chenopodiaceae and it is considered as a climate-smart crop. It has emerged as an ideal crop to tolerate high temperatures and poor soil in drought-prone and salinized agricultural areas because of its adaptability and ability to grow in harsh climatic conditions and its stability under different environmental conditions [8-10].

Quinoa grains are of high nutritional value because they contain high-quality protein where Quinoa grains are rich in essential amino acids, especially lysine, threonine and methionine. They also contain important unsaturated fatty acids (linoleic, linolenic, oleic); rich in minerals (iron, calcium, copper and zinc); and many vitamins [9,11,12]. Quinoa seeds contain 10:18% crude protein, 4.50:8.75% fat, 54.1:64.2% carbohydrates, 2.1:4.9% fiber and 2.40:3.65% ash and this variation is due to the diversity of genotypes [13]. The percentage of crude protein in quinoa is clearly higher than the percentage of protein in other field crops such as wheat, rice and corn [14]. Quinoa grains also have great importance in terms of their nutritional value because they do not contain gluten. Therefore, they are an important food source that meets the needs of protein and carbohydrates for people with gluten allergy [15].

Quinoa is suitable for children, the elderly, athletes, diabetics, celiac, gluten and lactose free thanks to its nutritional facts described for potential functional properties as a dietary supplement or alternative to common grains for human health. A review of the key aspects of quinoa as an alternative source of nutrient-dense gluten-free grains that have the potential to alleviate hunger and provide food security [16].

Wind fences are frequently used in many areas from agriculture to traffic safety in order to provide a sheltered region behind them. The conventional geometry of wind fences is usually porous material with circular or rectangular holes [17].

Porous fences represent a traditional mechanical method to control the migration of shifting sand toward neighboring downwind areas. The role of such fences is to decrease the rate of wind speed and reduce the cost of maintenance of the infrastructure fences, thus creating a good means for the establishment and growth of the vegetation cover located downwind of the fences. The role of mechanical fences for this concern is governed by the porosity of such fences [18,19].

The use of *theran* fences as an artificial protective system and using Napier grass as a biological protective system is important for improving the productivity and fruit quality of Earligrande peach cultivars under North Sinai conditions [5,6].

According to available reviews, no complete survey on the pests and diseases attacking quinoa in Egypt is available. The insects that attack quinoa were surveyed [20]. Two types of aphids, *Myzus persicae* and *Aphis gossypii* were detected as severe pests on quinoa in all governorates at all life stages. Two other sucking insects belonging to order Hemiptera were also detected in Ismailia Governorate only. One of these sucking insects belongs to the family Lygaeidae (*Nysius cymoides*), whereas the other pest belongs to family Miridae. In Faiyum only, a weevil belonging to Coleoptera, family Curculionidae, subfamily Curculioninae, was also detected on flowers and grains of quinoa during the late stage of growth (April and May). A shoot feeder, *Atherigona theodori* appeared in Ismailia and Faiyum and caused moderate losses in quinoa plants [20].

The application of silicon and kaolin in crops are a viable component of integrated pest management because it leaves no pesticide residues. It can also be easily integrated with other pest management practices, including biological control [21-23]. It is necessary to control pests with different methods such as using barriers and fences to limit disbursing insect pests, using kaolin as a barrier on the surface of leaves, and using potassium silicate to induce resistance of quinoa plants against insects [24,25].

Our study aims to evaluate the effect of two types of artificial fences on the microclimate, growth, and productivity of five quinoa genotypes, in addition to their efficiency for pest control of some quinoa genotypes grown under field conditions in Ismailia Governorate as an action to mitigate impact of climate change on agricultural production in Egypt.

Materials and Methods

Field conditions and genetic material

The study was conducted at Al-Salam Reagon, Ismailia Governorate (Cairo Ismailia Desert Road), during two successive winter growing seasons (2020/2021 and 2021/2022) to investigate the role of artificial fences (*theran* and reed) under the local climate in the farming area affected by aeolian deposits, in addition to their role in suppressing insect pests (cotton leafworm *Spodoptera littoralis* and *Aphis crassivora*) and promoting the growth and production of quinoa (*Chenopodium quinoa* Willd.) plants under field conditions. Table 1 summarizes the basic elements of the climatic conditions of the study area during two growing seasons.

The physical and chemical properties of the site's soil are presented in Tables 2 and 3. Soil samples were taken at different depth for determining soil pH in a 1:2.5 (soil: water) suspension using a Jennway pH meter according to McKeague [26]. Electrical conductivity was determined using a YS1 Model 35 Conductivity Meter according to the procedure of Richards [27]. Organic matter was determined according to Walkely [28].

Table 1: Climatic conditions during two growing seasons (2020/2021, 2021/2022) in Ismailia Governorate.

Month	First season					
	Wind speed (m/s)	Temperature (°C)			Air humidity (%)	Total rainfall (mm)
		Min	Ave	Max		
November	2.41	12.03	20.42	31.18	61.27	10.98
December	2.88	6.55	14.87	26.30	63.19	19.23
January	2.66	4.76	13.94	26.93	63.38	22.37
February	2.56	4.47	14.23	27.57	65.88	26.37
March	2.98	6.66	15.85	33.34	60.69	21.09
April	3.24	6.80	19.75	40.40	52.12	0.65
May	2.90	15.07	25.61	41.63	45.81	0.19
June	3.03	15.98	26.46	39.32	51.06	0
Second season						
November	2.34	12.45	20.73	32.97	62.38	11.54
December	2.76	6.65	14.39	25.40	64.81	18.94
January	3.16	4.76	13.94	26.93	68.25	26.37
February	2.49	4.47	14.23	27.57	66.94	0
March	3.23	6.66	15.85	33.34	61.31	73.83
April	2.98	6.8	19.75	40.4	61.12	94.92
May	3.00	15.07	25.61	41.63	55.12	0
June	3.18	16.07	26.78	42.11	56.02	0

Table 2: Physical properties of the site's soil in Ismailia Governorate.

Soil sample depth (cm)	Clay (%)	Silt (%)	Sand (%)		Texture class
			Coarse	Fine	
0-40	12.53	23.85	17.80	45.82	Sandy loam
0-20	6.62	16.52	25.64	51.22	Loamy sand
20-40	7.85	14.12	23.90	54.13	Loamy sand

Table 3: Chemical properties of the site's soil in Ismailia Governorate.

Chemical analysis	0-20 cm	20-40 cm	Soil mix (0-40 cm)
$CaCO_3$ (%)	-	-	-
OM* (%)	0.95	0.75	0.85
EC* ($dS\ m^{-1}$) of soil paste	2.95	2.95	5.10
pH in (1:2.5) extract	7.9	8.2	7.5
Soluble anions			
HCO_3^- (meq. L^{-1})	1.52	2.47	1.71
SO_4^{--} (meq. L^{-1})	9.78	13.63	20.39
Cl^- (meq. L^{-1})	18.2	14.4	38
Soluble cations			
Ca^{++} (meq. L^{-1})	7.8	7.3	22.9
Mg^{++} (meq. L^{-1})	6.54	7.04	7.80
Na^+ (meq. L^{-1})	14.5	14.5	26.5
K^+ (meq. L^{-1})	0.66	0.66	2.90
SAR* (%)	2.3	2.3	3.5

*OM: Organic Matter; EC: Electrical Conductivity; SAR: Sodium Adsorption Ratio; Not Detected.

Five quinoa genotypes (G 29 (CHEN-128), G 32 (CHEN-188), G 43 (CO-KA-1873), G 48 (CO-KA-1928), and G 74 (CO-KA-2300)) provided by the International Center for Biosaline Agriculture (ICBA) were used for the experiment.

Experimental design

Artificial fences, *theran* net (manufactured from polyethylene) having a shading potential of 73% and reed (manufactured from a compilation of dry *Phragmites australis* sticks) having a shading potential of 75%, were constructed on 1 October 2020 with 1.5 m height in a vertical angle with the prevailing wind direction and kept 3 m from the first row of quinoa genotypes (Figure 1). These fences were used for protection and their maintenance is required at least once every two years depending on seasonal wind speed.

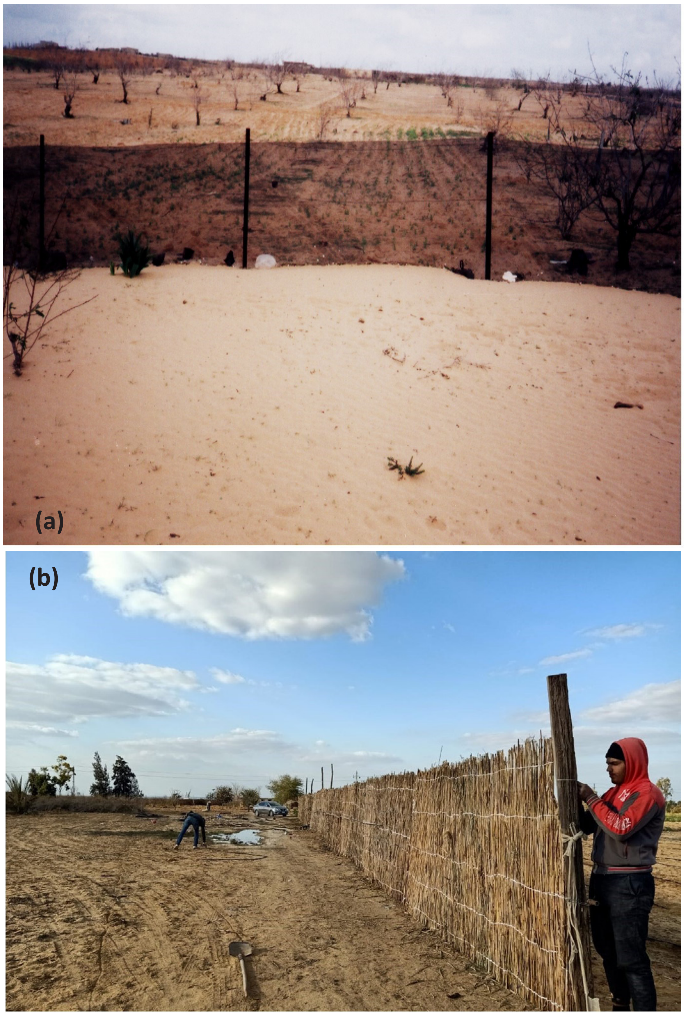


Figure 1: *Theran* fence **(a)** and Reed fence **(b)**.

The experimental design was a factorial experiment between fence treatments and quinoa genotypes in a split plot design (main plots were fence treatments and subplots were quinoa genotypes) with three replicates. Plot size was 6.3 m² (2.1 * 3.0), 20 cm plant to plant distance and 50 cm inter row spacing. The seeds of five quinoa genotypes were sown on November 26 (winter season) at a depth of 1.5: 2.0 cm in hills. After 22 days from sowing, the plants were thinned to two plants in hill.

Nitrogen fertilizer in the form of NH_4NO_3 was added as nitrogen sources (33.5% N) at a rate of 180 kg/ha, which was divided into three equal doses added after 20, 45 and 65 days, respectively, from the start of cultivation. Phosphate fertilizer was added in two doses before planning during soil preparation and the second dose after 30 days of planting in the form of superphosphate (48% P_2O_5) at a rate of 120 kg/ha in the form of tri-calcium phosphate, while potassium phosphate fertilizer was added in three doses before planting, after 30 days and 75 days of planting in the form of potassium sulfate (15% K_2O) at a rate of 120 kg/ha. 3030 m^3/ha of water was drip irrigation used throughout the season at a rate of 212 m^3/ha every 7 days. Irrigation was stopped two weeks before harvest.

Environmental factors

Data on the environmental factors (wind speed, soil temperature, and soil moisture) were recorded every 15 days to calculate the seasonal average for the two seasons of the investigation.

Wind speed and Fence efficiency

Wind speeds at various horizontal distances were measured by a hand anemometer with 0.5 m/h sensitivity. The anemometers were located 1.5 m aboveground at different distances from the fences as well as at distances on the windward and leeward sides as follows: -5 m, 10 m, and 15 m from the fences.

Fence efficiency was calculated based on the percentage of wind reduction on the windward and leeward sides at distances of 10 and 20 m from the different fences and the same line in open areas as follows:

Fence efficiency = [(wind speed on the windward side–wind speed on the leeward side)/wind speed on the windward side)] * 100

Soil temperature

Soil temperature was measured in the protected and open areas by a manual soil thermometer at distances of -5, 5, 10, and 15 m from the fences.

Growth parameters

Growth parameters for quinoa genotypes were measured from October to May for the study, including the following:

Germination ratio (%), plant height (m) as the average of 20 plants, leaf area (cm^2) using a leaf area apparatus (Cl-203 Area Meter CID, Inc.) as the average of 10 leaves, chlorophyll content (SPAD readings) using a MINOLTA chlorophyll meter SPAD-502, and grain yield/plant (g) as the average of 20 plants.

Insect observations for recorded data

Samples of 20 leaves from each replicate representing different levels and directions of the plants were randomly collected to investigate the insects that attack quinoa plants [29]. The samples of infested leaves and grains were collected to determine the level of infestation. The collected samples were kept in paper bags in a refrigerator until examination with the use of a binocular microscope. These samples were separated, identified, and counted. The percentage of reduction in infestation (R %) was calculated according to the formula of Topps and Wain [30] as follows: R (%) = [(C- T)/C] *100, where C=number of insects recorded in the control samples and T=number of insects recorded in the treatment samples.

Statistical analysis

The experimental design was a factorial experiment between fence treatments and quinoa genotypes in a split plot design (main plots were fence treatments and subplots were quinoa genotypes) with three replicates. Plot size was 6.3 m² (2.1 *

3.0), 20 cm plant to plant distance and 50 cm inter row spacing.

The data of our study were statistically analyzed and the differences between the means of the treatments were considered significant when they were more than the least significant differences at the 5% level according to Duncan's multiple range test [31] by using Statistix version 9 (Analytical Software, 2008).

Results

Effect of fences on microclimate

Wind speed

The data in Table 4 show that the fences significantly affected the average of seasonal wind speeds at distances of 10 m on the windward side and at 10 m and 20 m on the leeward side compared with the extended same line of the unprotected area. Their significant effect also extended to 20 m on the leeward side. However, the lowest (2.86 and 2.93 m/sec) and highest (3.73 and 3.94 m/sec) seasonal average wind speeds were recorded for 10 m on the leeward side and 10 m on the windward side in the first and second seasons, respectively.

The data showed significant differences in the average of seasonal wind speeds between the fences (Table 4). So, the highest average of seasonal wind speeds was recorded in the control area (3.94 and 3.94 m/sec), respectively, while the lowest average was gained with the *theran* fence (2.90 m/sec) in the first season and with the reed fence (2.99 m/sec) in the protected area in the second season.

The interaction (fences x distances) was significant in the two seasons. However, the lowest seasonal average wind speeds (2.27 and 2.38 m/sec) were achieved in the reed fence in the protected area at 10 m on the leeward side in both seasons, respectively.

Table 4: Effect of fences on average wind speed (m/sec) during two growing seasons (2020/2021 and 2021/2022).

Distance from fence Treatment	Before 10 m	After 10 m	After 20 m	Average
First season				
Theran fence	3.57 ^{c}	2.35 ^{f}	2.77 ^{e}	2.90 ^{B}
Reed fence	3.63 ^{c}	2.27 ^{g}	2.91 ^{d}	2.94 ^{B}
Control	3.99 ^{a}	3.97 ^{a}	3.87 ^{b}	3.94 ^{A}
Average	3.73 $^{A-}$	2.86 $^{C-}$	3.87 $^{B-}$	
Second season				
Theran fence	3.88 ^{b}	2.45 ^{e}	2.81 ^{d}	3.04 ^{B}
Reed fence	3.81 ^{c}	2.39 ^{f}	2.79 ^{d}	2.99 ^{C}
Control	3.94 ^{a}	3.96 ^{a}	3.92 ^{ab}	3.94 ^{A}
Average	3.88 $^{A-}$	2.93 $^{C-}$	3.17 $^{B-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

The data presented in Table 5 showed clearly that fences increased the wind reduction efficiency of protected areas compared with unprotected areas significantly in the two seasons. However, in both seasons, there was no significant difference between the two types of fences.

Regarding the distance from the fences on the leeward side, the highest reduction percentages were recorded at 10 m distance (24.33% and 24.79%), followed by 20 m distance (15.44% and 18.52%) in the first and second seasons, respectively.

Furthermore, on the leeward side at the distance of 10 m from the fences, the highest efficiency in the first season was recorded by the *theran* fence (34.17%), whereas, in the second season, the reed fence had the highest efficiency (37.37%).

Table 5: Percentage of wind speed reduction as affected by the fences during two growing seasons (2020/2021 and 2021/2022).

Distance from fence Treatment	After 10 m	After 20 m	Average
First season			
Theran fence	34.17 ^{b}	22.41 ^{c}	28.29 ^{A}
Reed fence	38.32 ^{a}	20.92 ^{c}	29.62 ^{A}
Control	0.50 ^{e}	3.00 ^{d}	1.75 ^{B}
Average	24.33 $^{A-}$	15.44 $^{B-}$	
Second season			
Theran fence	36.86 ^{a}	27.58 ^{b}	32.22 ^{A}
Reed fence	37.27 ^{a}	26.73 ^{b}	32.00 ^{A}
Control	0.25 ^{c}	1.26 ^{c}	0.76 ^{B}
Average	24.79 $^{A-}$	18.52 $^{B-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

Soil temperature

It is clear from Table 6 that the fences significantly decreased seasonal average soil temperatures in the protected areas at distances of 5 m and 10 m on the leeward side compared with 5 m distance on the windward side in the two seasons. Nevertheless, the lowest effect on soil temperature was obtained in both fences at 15 m distance.

Regarding distance from the fences, soil temperature in the two seasons was significantly affected with distances of 5 m and 10 m from the fences on the leeward side. Generally, soil temperature gradually increased by increasing the leeward distance from the fence. Nonetheless, the lowest (26.4 and 25.9 °C) and highest (28.6 and 28.4 °C) seasonal average soil temperatures were gained at 5 m on the leeward and windward sides in the two seasons, respectively.

Table 6: Effect of different protective systems on average soil temperature (°C) during two growing seasons (2020/2021 and 2021/2022).

Distance from fence Treatment	Before 5 m	After 5 m	After 10 m	After 15 m	Average
First season					
Theran fence	28.7 ^{a}	25.1 ^{d}	26.4 $^{c\text{-}d}$	27.9 $^{a\text{-}c}$	27.0 ^{B}
Reed fence	28.5 ^{ab}	25.2 ^{d}	25.8 ^{d}	26.8 $^{b\text{-}d}$	26.6 ^{B}
Control	28.7 ^{a}	29.0 ^{a}	29.1 ^{a}	28.7 ^{a}	28.9 ^{A}
Average	28.6 $^{A-}$	26.4 $^{C-}$	27.1 $^{BC-}$	27.8 $^{AB-}$	
Second season					
Theran fence	28.6 ^{a}	25.3 ^{cd}	26.8 ^{bc}	27.9 ^{ab}	27.1 ^{B}
Reed fence	28.5 ^{a}	24.2 ^{d}	25.6 ^{cd}	26.3 ^{c}	26.2 ^{C}
Control	28.1 ^{ab}	28.3 ^{ab}	28.5 ^{a}	28.3 ^{ab}	28.3 ^{A}
Average	28.4 $^{A-}$	25.9 $^{C-}$	27.0 $^{B-}$	27.5 $^{B-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

Effect of fences on growth parameters

Germination ratio

Considering the fence type only, Table 7 and Figure 2 show that the tested fences significantly affected the germination ratio of quinoa genotypes in the two seasons. However, the highest significant values of germination ratio were recorded in the protected areas with *theran* fence (86.152%) in the first season and with reed fence (86.798%) in the second season compared with the unprotected areas (81.055% and 80.978%) in both seasons, respectively.

It is quite evident from Table 7 and Figure 2 that, by comparison of genotypes only, the highest germination ratio (99.48% and 99.24%) was achieved with G74, followed by G28 (87.28% and 88.80%), but the lowest germination ratio (73.84% and 74.51%) was gained by G32 in the first and second seasons, respectively.

The interaction between fences and genotypes showed that germination ratio was significantly affected by the treatments. So, the highest germination ratio (100% and 100%) was achieved with G74 that was protected by *theran* and reed fences. The lowest germination ratio (70.33% and 70.20%) was obtained with unprotected G32 in the first and second seasons, respectively.

Table 7: Effect of fences on germination ratio of genotype seeds during two growing seasons (2020/2021 and 2021/2022).

Treatment Genotype	Control	Reed	*Theran*	Average
First season				
G29	81.57 ^{d}	90.00 ^{b}	90.26 ^{b}	87.276 ^{B}
G32	70.33 ^{i}	75.00 ^{gh}	76.20 $^{f-h}$	73.843 ^{E}
G43	73.61 ^{hi}	77.00 ^{fg}	78.36 ^{ef}	76.324 ^{D}
G48	81.30 ^{gh}	84.75 ^{c}	85.94 ^{c}	83.996 ^{C}
G74	98.47 ^{a}	100.00 ^{a}	100.00 ^{a}	99.489 ^{A}
Average	81.055 $^{B-}$	85.350 $^{A-}$	86.152 $^{A-}$	
Second season				
G29	81.90 ^{de}	93.60 ^{b}	90.90 ^{b}	88.802 ^{B}
G32	70.20 ^{j}	76.48 ^{hi}	76.86 $^{g-i}$	74.513 ^{E}
G43	74.08 ^{i}	78.40 $^{f-h}$	79.44 $^{e-g}$	77.308 ^{D}
G48	80.98 ^{ef}	85.50 ^{c}	84.38 ^{cd}	83.620 ^{C}
G74	97.73 ^{a}	100.00 ^{a}	100.00 ^{a}	99.244 ^{A}
Average	80.978 $^{B-}$	86.798 $^{A-}$	86.317 $^{A-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

Plant height

Plant height according to fence type only during both seasons is presented in Table 8 and Figure 3. Plant height showed a significant increase with the fence treatments in both seasons. The highest plant height was recorded with the plants protected by *theran* fence (73.865 and 86.273 cm) followed by reed fence (73.56 and 85.2 cm) in the first and second seasons, respectively. Moreover, the unprotected plants showed the lowest plant height (70.2 and 74.8 cm) in the first and second seasons, respectively.

The tallest plants in the comparison of genotypes were for G48 (97.62 and 105.62 cm) and the shortest for G32 (52.40 and 60.03 cm) in the first and second seasons, respectively.

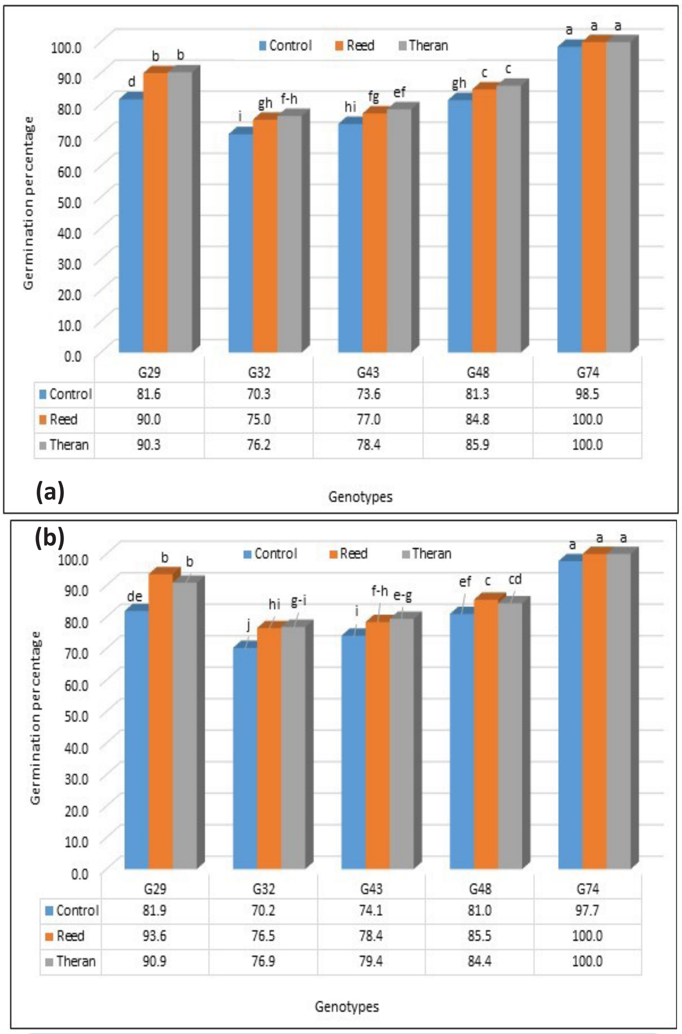


Figure 2: Effect of fences on genotype germination percentage for season 2020/2021 **(a)** and season 2021/2022 **(b)**. Abbreviations: mean values ± standard errors; a, b, c, d, e, f-homogeneous groups according to Duncan's multiple range test at level P=0.05.

Table 8: Effect of fences on plant height (cm) of genotype seeds during two growing seasons (2020/2021 and 2021/2022).

Treatment Genotype	Control	Reed	*Theran*	Average
First season				
G29	76.00 ^{e}	79.77 ^{d}	80.23 ^{cd}	78.67 ^{C}
G32	51.00 ^{fg}	53.23 ^{f}	52.97 ^{f}	52.40 ^{D}
G43	80.33 ^{cd}	82.71 ^{cd}	83.38 ^{c}	82.14 ^{B}
G48	94.67 ^{b}	99.14 ^{a}	99.04 ^{a}	97.62 ^{A}
G74	49.00 ^{g}	52.96 ^{f}	53.71 ^{f}	51.89 ^{G}
Average	70.20 $^{B-}$	73.56 $^{A-}$	73.87 $^{A-}$	
Second season				
G29	69.33 ^{de}	83.33 ^{bc}	85.00 ^{bc}	79.22 ^{B}
G32	53.00 ^{f}	63.00 ^{ef}	64.10 ^{ef}	60.03 ^{C}
G43	79.00 ^{cd}	86.00 ^{bc}	86.17 ^{bc}	83.72 ^{B}
G48	94.67 ^{b}	110.77 ^{a}	111.43 ^{a}	105.62 ^{A} 81.86 ^{B}
G74	78.00 ^{cd}	82.90 ^{bc}	84.67 ^{bc}	
Average	74.80 $^{B-}$	85.20 $^{A-}$	86.27 $^{A-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

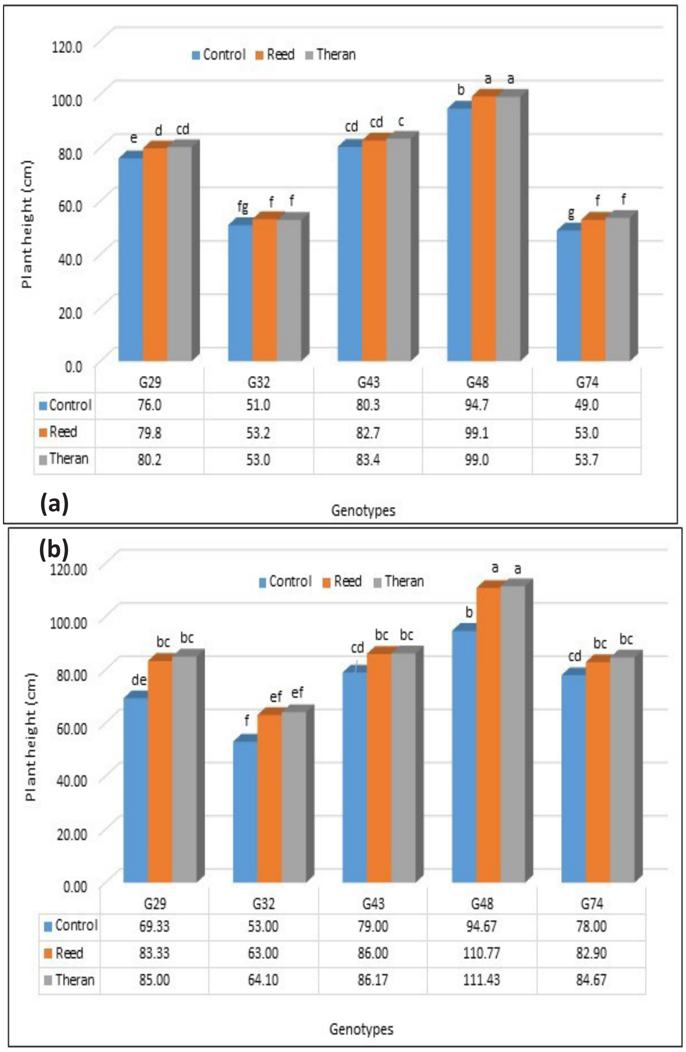


Figure 3: Effect of fences on genotype plant height (cm) for season 2020/2021 **(a)** and season 2021/2022 **(b)**. Abbreviations: mean values ± standard errors; a, b, c, d, e, f-homogeneous groups according to Duncan's multiple range test at level P=0.05.

Leaf area

The recorded results for fence type effect only during the two growing seasons showed that the fences increased the leaf area of the genotype plants compared with the unprotected plants during both seasons (Table 9 and Figure 4).

The highest leaf area (11.294 and 11.472 cm^2) was recorded for plants protected with *theran* fence compared with unprotected plants (9.771 and 9.732 cm^2) in the first and second seasons, respectively.

The highest leaf area when comparing genotypes was obtained with G74 (16.771 and 16.772 cm^2). Nevertheless, the lowest leaf area was achieved with unprotected plants in the first and second seasons, respectively.

Chlorophyll content

Table 10 and Figure 5 showed clearly that the total leaf chlorophyll content was significantly affected by the *theran* fence in the two seasons and by the reed fence in the first season only. However, regarding the effect of fences only, the highest total leaf chlorophyll content (SPAD readings) was achieved with the protected plants with the *theran* fence (45.674 and 45.919), but the lowest content was achieved with the unprotected plants (43.97 and 42.43) in the first and second seasons, respectively.

Table 9: Effect of fences on genotype leaf area (cm2) during two growing seasons (2020/2021 and 2021/2022).

Treatment Genotype	Control	Reed	*Theran*	Average
First season				
G29	7.363 ^{g}	8.740 ^{ef}	8.660 ^{ef}	8.254 ^{C}
G32	7.383 ^{g}	8.990 ^{ef}	9.107 ^{e}	8.493 ^{C}
G43	10.757 ^{d}	12.550 ^{c}	12.710 ^{c}	12.006 ^{B}
G48	7.607 ^{g}	8.390 ^{f}	8.557 ^{ef}	8.184 ^{C}
G74	15.747 ^{b}	17.130 ^{a}	17.437 ^{a}	16.771 ^{A}
Average	9.771 $^{B-}$	11.160 $^{A-}$	11.294 $^{A-}$	
Second season				
G29	7.393 ^{f}	8.820 ^{e}	9.100 ^{e}	8.438 ^{C}
G32	7.523 ^{f}	9.200 ^{e}	8.903 ^{e}	8.542 ^{C}
G43	10.520 ^{d}	12.600 ^{c}	12.807 ^{c}	11.976 ^{B}
G48	7.547 ^{f}	8.617 ^{e}	9.290 ^{e}	8.484 ^{C}
G74	15.677 ^{b}	17.230 ^{a}	17.260 ^{a}	16.722 ^{A}
Average	9.732 $^{B-}$	11.293 $^{A-}$	11.472 $^{A-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

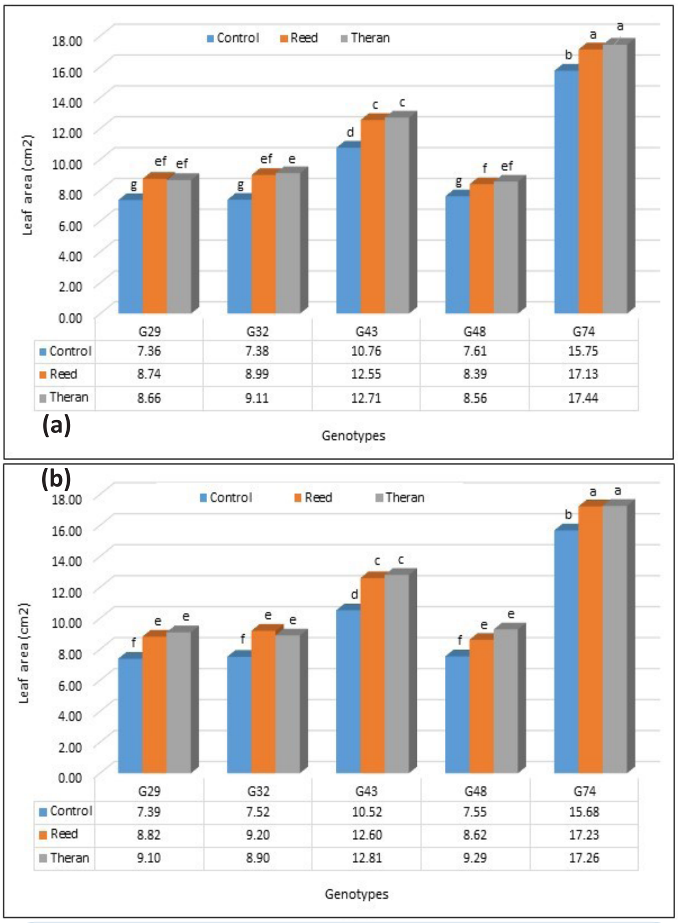


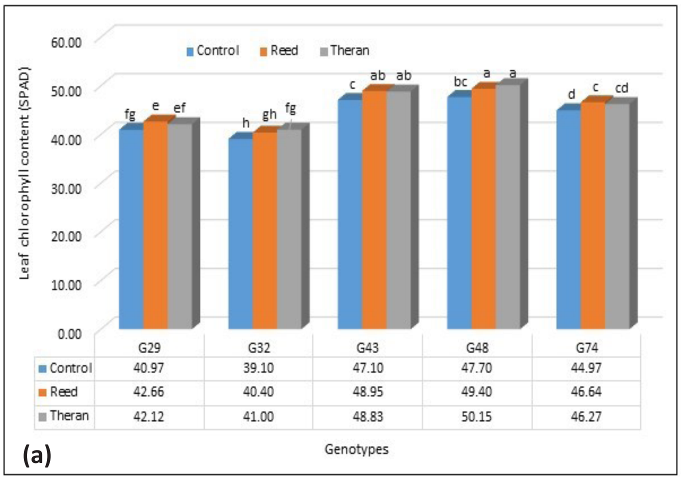
Figure 4: Effect of fences on genotype leaf area (cm2) during season 2020/2021 **(a)** and season 2021/2022 **(b)**. Abbreviations: mean val-ues ± standard errors; a, b, c, d, e, f-homogeneous groups according to Duncan's multiple range test at level P=0.05.

The comparison of leaf chlorophyl content among genotypes showed that the highest total leaf chlorophyll content (49.084 and 49.484 SPAD readings) was gained by G48 plants. The lowest total leaf chlorophyll content (40.169 and 40.574 SPAD readings) was reported for G32 plants in the first and second seasons, respectively.

Table 10: Effect of fences on genotype total leaf chlorophyll content (SPAD readings) during two growing seasons (2020/2021 and 2021/2022).

Treatment Genotype	Control	Reed	*Theran*	Average
First season				
G29	40.970 ^{fg}	42.663 ^{e}	42.117 ^{ef}	41.917 ^{C}
G32	39.103 ^{h}	40.403 ^{gh}	41.000 ^{fg}	40.169 ^{D}
G43	47.103 ^{c}	48.950 ^{ab}	48.833 ^{ab}	48.296 ^{A}
G48	47.703 ^{bc}	49.397 ^{a}	50.153 ^{a}	49.084 ^{A}
G74	44.970 ^{d}	46.637 ^{c}	46.267 ^{cd}	45.958 ^{B}
Average	43.970 $^{B-}$	45.610 $^{A-}$	45.674 $^{A-}$	
Second season				
G29	40.947 ^{d}	43.167 $^{a-e}$	42.673 $^{a-e}$	42.262 ^{BC}
G32	39.053 ^{de}	40.990 c-e	41.680 $^{b-e}$	40.574 ^{C}
G43	38.363 ^{e}	48.567 $^{a-c}$	48.860 ^{ab}	45.263 ^{AB}
G48	48.757 ^{ab}	49.700 ^{a}	49.997 ^{a}	49.484 ^{A}
G74	45.047 $^{a-e}$	46.540 $^{a-d}$	46.387 $^{a-d}$	45.991 ^{AB}
Average	42.433 $^{B-}$	45.793A $^{B-}$	45.919 $^{A-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.



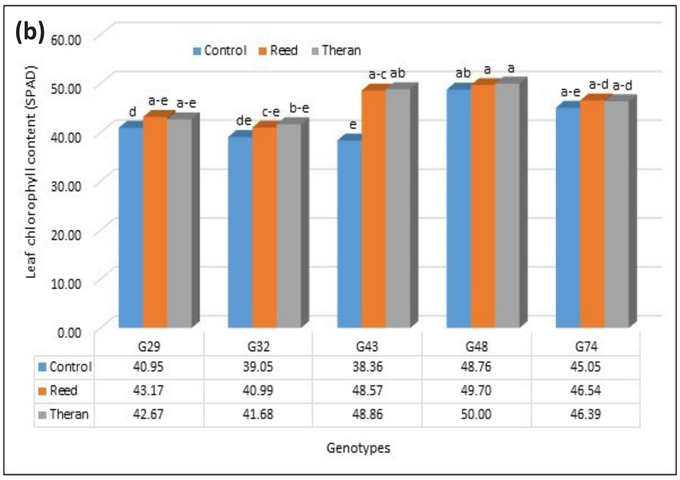


Figure 5: Effect of fence treatment on leaf chlorophyll content (SPAD readings) for the different genotypes during season 2021 **(a)** and season 2022 **(b)**. Abbreviations: mean values ± standard errors; a, b, c, d, e, f—homogeneous groups according to Duncan's mul-tiple range test at level P=0.05.

Yield per plant

The effect of fence type only on plant grain yield is presented in Table 11 and Figure 6. The results showed that the yield/plant of the protected plants increased significantly compared with the yield of the unprotected plants in the first and second seasons.

Protected quinoa plants with *theran* fence showed the highest significant values (38.335 and 41.549 g/plant) compared with the control (32.703 and 32.97 g/plant) in the first and second seasons, respectively.

Depending on the genotype comparison, the highest yield/plant (48.427 and 48.577 g) was recorded for G48, followed by G74 (40.101 and 40.549 g). The lowest values were recorded for G32 (25.502 g) in the first season and for G29 (29.012 g) in the second season.

Table 11: Effect of fences on genotype grain yield/plant (g/plant) during two growing seasons (2020/2021 and 2021/2022).

Treatment Genotype	Control	Reed	*Theran*	Average
First season				
G29	26.343 ^{g}	29.100 ^{f}	29.203 ^{f}	28.216 ^{C}
G32	23.280 ^{h}	26.423 ^{g}	26.803 ^{g}	25.502 ^{D}
G43	33.550 ^{e}	41.703 ^{c}	41.727 ^{c}	38.993 ^{B}
G48	44.123 ^{b}	50.200 ^{a}	50.957 ^{a}	48.427 ^{A}
G74	36.217 ^{d}	41.103 ^{c}	42.983 ^{bc}	40.101 ^{B}
Average	32.703 $^{B-}$	37.706 $^{A-}$	38.335 $^{A-}$	
Second season				
G29	27.103 ^{cd}	30.253 ^{cd}	29.680 ^{cd}	29.012 ^{C}
G32	23.320 ^{d}	28.200 ^{cd}	42.193 ^{ab}	31.238 ^{C}
G43	34.100 $^{b-d}$	42.137 ^{ab}	42.273 ^{ab}	39.503 ^{B}
G48	44.123 ^{ab}	50.537 ^{a}	51.070 ^{a}	48.577 ^{A}
G74	36.203 ^{bc}	42.787 ^{ab}	42.527 ^{ab}	40.506 ^{B}
Average	32.970 $^{B-}$	38.783 $^{A-}$	41.549 $^{A-}$	

Abbreviations: mean values ± standard errors; a,b,c,d,e,f - homogene -ous groups according to Duncan's multiple range test at level P=0.05.

Effect of fences on some insect infestations

Using fences is an important method for protecting plants from biotic and abiotic stresses. Insects cause biotic stress on quinoa plants, so this study is important for investigating the role of artificial fences (*theran* and reed) in the local climate in farming areas affected by insects as well as for enhancing quinoa growth and productivity under field conditions.

Effect of fences on cotton leafworm *Spodoptera littoralis*

Table 12 summarizes the records of cumulative infestation by cotton leafworm during seasons 2020/2021 and 2021/2022. The results indicated that infestation was significantly lower in the treated plants than in the untreated ones. The results indicated variations among the treatments in reduction percentage and infestation levels of cotton leafworm of quinoa plants. The area protected by *theran* fence showed more protection than the area protected by reed fence in protecting quinoa plants from cotton leafworm infestations of leaves and larvae. Infestation decreased by 11.4% to 23.7% in the first and second season, respectively.

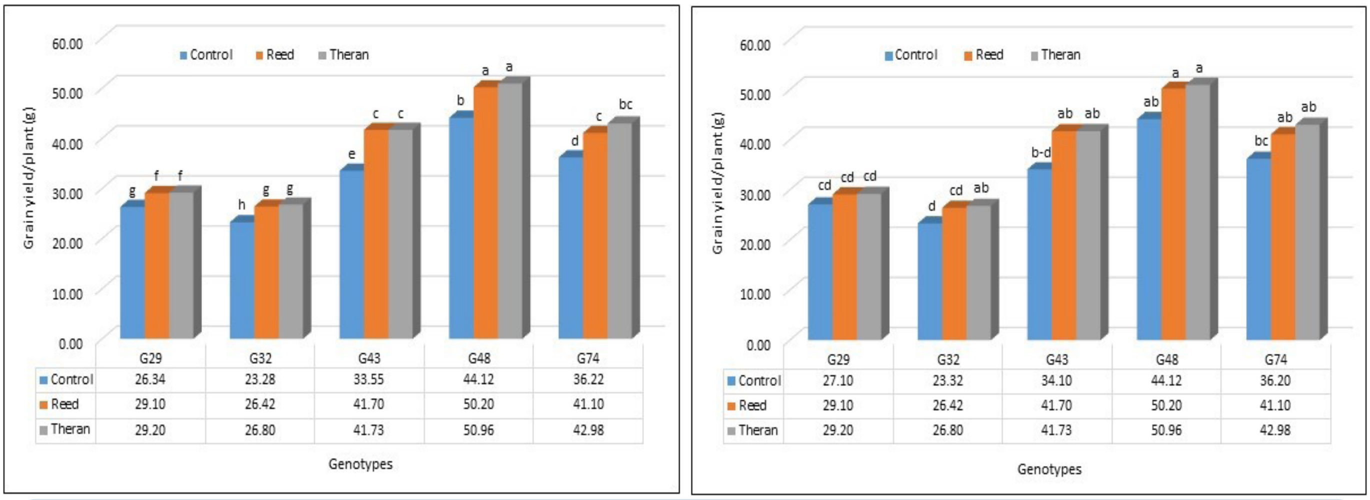


Figure 6: Effect of fence treatment on plant grain yield for the different genotypes during season 2020/2021 **(a)** and season 2021/2022 **(b)**. Abbreviations: mean values ± standard errors; a, b, c, d, e, f-homogeneous groups according to Duncan's multiple range test at level P=0.05.

Table 12: Cumulative infestation by cotton leafworm *Spodoptera littoralis* in quinoa groves under area protected by fences throughout seasons 2020/2021 and 2021/2022.

Genotypes	Infestations (%) during 2021 season									
	Leaves					Larvae				
	Control	Reed		*Theran*		Control	Reed		*Theran*	
		Mean	R %	Mean	R %		Mean	R %	Mean	R %
G29	10.0	8.2	18.0	8.0	20.0	6.0	5.0	16.7	4.0	20.0
G32	5.0	4.2	16.0	4.1	18.0	3.7	3.2	13.5	2.7	15.6
G43	7.2	6.1	15.3	5.5	23.6	5.0	4.3	14.0	3.4	20.9
G48	3.8	3.0	21.1	2.9	23.7	3.0	2.5	16.7	2.0	20.0
G74	4.4	3.8	13.6	3.6	18.2	3.5	3.1	11.4	2.6	16.1
Genotypes	Infestations (%) during 2022 season									
	Leaves					Larvae				
	Control	Reed		*Theran*		Control	Reed		*Theran*	
		Mean	R %	Mean	R %		Mean	R %	Mean	R %
G29	10.5	8.2	21.9	8.0	23.8	7.0	6.0	14.3	4.6	23.3
G32	5.6	4.6	17.9	4.4	21.4	4.0	3.5	12.5	2.9	17.1
G43	8.3	7.0	15.7	6.4	22.9	5.5	4.6	16.4	3.6	21.7
G48	4.2	3.2	23.8	3.2	23.8	3.8	3.1	18.4	2.5	19.4
G74	4.9	4.3	12.2	3.8	22.4	4.0	3.5	12.5	2.9	17.1

R % = Reduction percentage.

Effect of fences on aphid *Aphis crassivora*

The data of the cumulative infestation by aphid (Table 13) show that treated plants have significantly lower values than untreated plants. Quinoa plants were evaluated for aphid infestation before erection of fences, resulting in aphid clusters. Therefore, the influence of the original population on the results across treatments can be ignored. From this we can conclude that fences exhibit different control effects on quinoa aphids.

The quinoa plants treated with *theran* fences exhibited a less moderate decrease in aphid populations, which was statistically similar to that of the infestation prior to the treatment. Among the fences tested, the *theran* fences produced a greater reduction in the leaves than the reed fences, which reduced the infestations less moderately, with a reduction percentage from 11.0 to 28.0 in the two seasons.

Discussion

Effect of fences on microclimate

Wind speed

Wind and its speed are among the important factors determining the success of cultivating different crops, as an increase in wind speed in the cultivation area leads to a decrease in growth and yield and could lead to uprooting of plants. Many previous studies were applied to mitigate the adverse environmental conditions that affect the growth and productivity of crops grown under aeolian deposit conditions.

Reducing wind speed as a result of protective systems (artificial fences, windbreaks, and shelterbelts) was previously reported by several studies conducted in Egypt [4,5] and, and other countries [17,32,33] and they are in line with the findings of the current study.

Table 13: Cumulative infestation by aphid *Aphis crassivora* in quinoa groves under area protected by fences throughout seasons 2020/2021 and 2021/2022.

Genotype	Control	Reed		*Theran*	
		Infestation (%) during 2021 season			
		Mean	R %	Mean	R %
G29	14.1	11.5	18.4	12.2	13.5
G32	18.2	15.9	12.6	15.0	17.6
G43	16.7	13.5	19.2	13.0	22.2
G48	20.8	18.2	12.5	15.8	24.0
G74	19.6	16.9	13.8	14	28.6
		Infestation (%) during 2022 season			
Genotype	**Control**	**Reed**		***Theran***	
		Mean	R %	Mean	R %
G29	15.0	11.5	23.3	13.0	13.3
G32	17.5	15.0	14.3	15.0	14.3
G43	18.2	15.0	17.6	14.0	23.1
G48	21.4	19.0	11.2	16.0	25.2
G74	20.6	18.0	12.6	15.6	24.3

The percentage of sand trapped, and wind reduction varied depending on fence type, porosity, and height. However, the functional effects of windbreaks are directly related to the effects of windbreaks on air flow [34-36].

A similar result was obtained by Zaghloul [37], who studied the effect of single and double rows of palm leaves and *theran* fences and found that their effectiveness ranged from 27% to 50% in trapping sand because of the reduction in wind speed.

It is worthwhile to mention that in our current study, fences were quite effective in improving microclimate in both seasons and, generally, the *theran* and reed fences had the same effect in both seasons.

Soil temperature

The studied fences significantly affected the seasonal average soil temperatures in the protected areas. Windbreaks have long been recognized for their effects on the soil temperature [38]. Soil temperatures in the protected areas were reported significantly lower than in the open areas in many studies in Egypt in West Nubaria region [4,39].

Black and Aase [40] reported that the microclimate effects of the tall wheatgrass (*Agropyron elongatum* L.) barriers relative to open-field environments include (1) increased soil temperature in early spring and (2) decreased soil temperature in June due to greater crop canopy. Therefore, the protective influence of tall wheatgrass barriers increased soil temperature clearly, with slight increases near the barriers in the spring. It has been reported as well that the surface soil temperatures were higher in spring and summer and lower in fall and winter in the sheltered fields than in the unsheltered fields [39]. Simal study by Aase and Siddoway [41] on the perennial herbaceous barriers showed that later in the season, the soil temperature became higher in the check area than in the barrier system.

On the other hand, the differences in soil temperatures among the treatments (i.e., building corn straw fencing, placing wheat straw checkerboard, planting *Artemisia halodendron*, and control) were shown not statistically significant [42].

El-Gamal [5] reported in his study on peach trees in North Sinai that the *theran* and plastic fences significantly reduced seasonal average soil temperatures in the protected areas at distances of 5 m, 10 m, and 15 m on the leeward side compared with 5 m distance on the windward side as a result of decrease in the speed of cold winds.

Effect of fences on growth parameters

The use of fences improved the plant growth and yield of all studied quinoa genotypes with a greater effect of *theran* net compared with reed fences.

The interaction between fences and genotypes showed that germination ratio was significantly affected by the protection treatments. The use of fences significantly increased the germination rate in both seasons with better effect of *theran* net. Same trend noted for the plant height which is increased for the genotypes grown in protected areas.

Similar studies on the effect of single and double rows of palm leaf fences on alfalfa crops in Siwa reported that the fences significantly increased plant height compared with the control (without fences); however, this increase decreased as the distance between plants and fences increased [37]. In the other hand, other studies in North Sinai reported an increase in peach tree height occurred due to protection with an artificial system containing two polyethylene fences with different porosity, namely, *theran* net and plastic net, with 27% and 52% porosity, respectively [5].

Protection by fences and windbreaks led to an increase in the growth parameters of the protected plants as well as leaf area, and this is what was achieved with Heiligmann and Schneider [38] in black walnut seedlings, Grace [43] in many crops, Hegazi et al. [44] in grapevines, Elkarbotly [45] in olive, Rosenberg [46] in bean, Marshall [47] in sugar beets, Aase and Siddoway [41] in winter wheat, and El-Gamal [5] in peach.

The use of both fences *theran* and reed net increased the total chlorophyll content of the quinoa leaves measured as SPAD readings. Similar studies in Egypt reported that the total chlorophyll content increased significantly in trees protected by fences compared with unprotected trees and that is what was found by Elkarbotly [45] in olive leaves and by El-Gamal [5] in peach leaves.

The reported increase of yield per plant under the fences protected treatments is in accordance with previous studies on fruit trees and forage crops. The effects of the windbreaks and barriers relative to open-field environments increased the yields of various studied fruit species such as Thompson seedless grapevine [4, 44], olive trees [45], and peach trees [5]. A similar result was obtained with a study on the effect of single and double rows of palm leaf fences on an alfalfa crop, which reported that the fences significantly increased green and dry forage yield compared with the control (without fences) [37]. Single and double rows of wood fences also enhanced the grain yield, quality, and harvest index of protected wheat plants (*Triticum aestivum*, variety *Buck Charrua*) [48].

Effect of fences on some insect infestations

The use of fencing significantly improved the protection of quinoa from cotton leafworm and aphids. Theran fences were more effective than reed fences and had a greater impact on reducing pest infestation in the second season, with cotton leafworm and aphid infestation each reduced by at least 25%. Similar results were shown in tomato plants protected with fine mesh environmental nets (0.4 mm pore size), large mesh EFN (0.9 mm pore size) or FRC [49]. The use of green netting (EFN) in shaded cultivation in Africa was tested and found to be effective against several cabbage pests (Brassica oleracea L. var. capitata L.) [50,51]. Floating Row Cover (FRC) is an effective pest control agent that is effective against a wide range of pests including aphids, cucumber beetles (Acalymma and Diabrotica sp.), whiteflies and related pathogens, and has also demonstrated their ability to act as a physical barrier against Pest Capabilities [52].

As a result of pest exclusion, covers have potential for diminishing pesticide application in any given crop, thus providing a more environmentally friendly alternative for controlling insect pests among small-holding farmers. Cover pore diameter affects the entry of insect pests into the crops. This probably explains the lower population of pests observed under covers with finer pore diameter (FRC and 0.4-mm EFN) compared with those of a larger pore diameter (0.9-mm EFN). In their field tests, Martin et al. and Licciardi et al. [50,51] similarly observed delayed and reduced aphid infestation in cabbage under netting.

Conclusions

The use of artificial fences of *theran* and reeds in the study area that is exposed to aeolian deposits significantly improved the microclimate by reducing the average wind speed by 34.17% and 37.37% and by increasing the soil temperature (2.2-2.5 °C) on the leeward side of the fences, whereas wind speed increased, and soil temperature decreased gradually by increasing the leeward distance from the fences.

This improvement in microclimate led to an increase in the percentage of germination, plant length, leaf area, chlorophyll content, and yield of all tested quinoa genotypes. In addition, it helped to diminish the incidence of cotton leafworm and aphid infestation in protected quinoa plants, which was more obvious with the use of the *theran* fence.

The overall results reveal that the use of artificial wind fences improves the plant microclimate, which leads to better plant growth, and this can be an effective agricultural practice for integrated pest management.

Author contributions: HEEG and AB designed the research and AE conducted the experiment and analysis. HEEG wrote the initial draft of this manuscript and conceived the original ideas. HEE, HM, EA, and AB contributed to idea refinement, writing, and revising of the manuscript. AB supervised the work and HM revised and finalized the manuscript. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: This work has been supported by the International Center for Biosaline Agriculture (ICBA) as part of the project Developing a User-Friendly Application for Smallholder Farmers for Detection of Plant Disorders.

Conflicts of interest: The authors declare no conflict of interest.

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