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Preliminary Evaluation of New Quinoa Genotypes under Sandy Soil Conditions in Egypt

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Abstract

Field trial was carried out at Ismailia Research Station, Ismailia Governorate, Egypt to evaluate some quinoa genotypes under arid environment of sandy soil for identifying its agronomic potentiality, chemical composition and economic opportunity. Nine quinoa genotypes including six Peruvian varieties (Amarilla Marangani, Amarilla Sacaca, Blanca de Junin, Kancolla, Salcedo INIA and Rosada de Huancayo) and three new accessions (QS14, QS16 and QS17-2) were compared in randomized complete block design with three replications. The results revealed that quinoa proved success in sandy soil with suitable grain yield under Egyptian conditions. QS17-2 accession stays only from 115 to 120 days in the field according to environmental factors and treated as short duration accession, while growth duration of the four varieties; Blanca de Junin, Kancolla, Salcedo INIA and Rosada de Huancayo, as well as, accessions of QS14 and QS16 were moderate. Amarilla Marangani and Amarilla Sacaca varieties had the longest duration genotypes. Amarilla Sacaca and Amarilla Marangani varieties, as well as, QS17-2 accession gave the highest grain yield compared with the other genotypes. The highest protein content in quinoa grains was 13.60%, which recorded from QS17-2 accession, while the lowest value (10.75%) was recorded by Blanca de Junin variety. Moreover, Salcedo INIA variety had the lowest saponins content in quinoa grains (0.07%) while QS16 accession recorded the highest content (0.22%). The economic evaluation gave a clear indicator of the lower farm prices of quinoa grains in Egypt (US$ 1000/ton), which gives a comparative advantage to Egypt in the MENA region for quinoa exportation.

Keywords

Quinoa Genotypes, Grain Yield, Protein, Saponins, Economic Evaluation

1. Introduction

Always, population growth requires an increase in the use of available environmental resources around the world. It is considerable pressure on available environmental resources especially water that is one of the major factors in arid and semiarid regions [1]. So, it is important to address our efforts to this fundamental issue by increasing food supply to face the highest population growth rates without any increase in the used water duty especially in the developing countries. According to FAO [2], there were around 799 million undernourished people in the developing countries. Recently, quinoa (*Chenopodium quinoa* Willd.) crop has attracted attention of the Food and Agriculture Organization of the United Nations (FAO) to fight hunger in the 21st century because of its high nutritional value and extreme resistance to adverse environmental conditions.

From several decades, quinoa is a valuable source of protein in some parts of South America; it was cultivated and used by the Inca (ruling class) people since 5000 B.C. It is consumed in wide variety of forms *i.e.*, grains, flakes, pasta, bread, biscuits, beverages, meals etc. Bolivia in South America is the biggest producer of quinoa with 46 percent of world production followed by Peru with 42 percent and United States of America with 6.3 percent. Quinoa is cultivated in the world with an area of 126 thousand ha with a production of 103 thousand ton [3]. Thus, it is likely to be exploited further in both developing and industrialised countries.

So, NASA [4] selected this crop as ideal candidate crop for the Controlled Ecological Life Support System (CELSS). Quinoa can be used to produce gluten-free cereal-based products, and can thus be eaten by people who have celiac disease, as well as, by those who are allergic to wheat because of the absence of gluten proteins [5]. Quinoa have high protein values and essential amino acids including (lysine), fats, flavonoids, vitamins and minerals and as a gluten-free product [6]. Due to the high nutritional value of quinoa, it has been considered an exceptional crop with the potential of contributing to food security worldwide because of its genetic diversity and its great adaptability to stressful environments [7].

Although several cultivars of quinoa contain saponins act as antinutrients, frequently associated with lipids [8], some saponins can form insoluble complexes with minerals, such as zinc and iron, which make the minerals unavailable for absorption in the gut [9]. It is known that saponins in quinoa are basically glycosidic triterpenoids with glucose constitution about 80% of the weight [10] and concentrated in seed hull [11].

Therefore, several countries in all over the world started in the last years to promote researches for the development of quinoa cultivation; especially the genetic variability of quinoa is huge, with cultivars of quinoa being adapted to growth from sea level to an altitude of over 4000 meters and from cold, highland climates to subtropical conditions. This make it possible to select, adapt, and breed cultivars for a wide range of environmental conditions such as arid or humid areas, cold or hot environments, acidic or alkaline soils [12]. Consequently, FAO declared that year 2013 was the international year of quinoa [13]; where this foundation contributed positively to food and nutritional security not only in Egypt but also in Algeria, Iraq, Iran, Lebanon, Mauritania, Sudan and Yemen by supporting of inclusion a new promising quinoa varieties, technology transfer and training program through QUINOA PROJECT-TCP/RAB/3403 "Technical assistance for the introduction of quinoa and appropriation/institutionalization of its production". However, the improvement of quinoa seed quality is challenging and key for food security and has been almost exclusively focused on generating hybrid varieties with lower saponin contents [14].

Accordingly, breeding programs in quinoa should be mainly focused on the generation of better environmentally adapted plants with higher protein and lower saponin contents to develop high-yielding varieties. Evaluation of new introduced accessions, varieties and new accessions resulted from natural crosses among various genotypes is an important target to release new varieties for Egyptian farmers. Hence, growing quinoa can save hard currency by replenishing part of food gap since the crop succeeded to grow economically in new reclaimed sandy soils of Egyptian deserts [15] [16]. Therefore, the objective of this investigation was to evaluate some quinoa genotypes under arid environment of sandy soil for identifying its agronomic potentiality, chemical composition and economic opportunity.

2. Materials and Methods

Field trial was carried out at Ismailia Agricultural Research Station, Ismailia Governorate (Lat. 30˚35'30"N, Long. 32˚14'50"E, 10 m above the sea level), Egypt during 2014/2015 and 2015/2016 winter seasons to evaluate some quinoa genotypes under arid environment of sandy soil for identifying its agronomic potentiality, chemical composition and economic opportunity. Nine quinoa genotypes including six Peruvian varieties (Amarilla Marangani, Amarilla Sacaca, Blanca de Junin, Kancolla, Salcedo INIA and Rosada de Huancayo) and three new accessions (QS14, QS16 and QS17-2) were compared in randomized complete block design with three replications. **Table 1** shows origin and grain color of the nine quinoa genotypes used in the trial.

Table 1. Origin and grain color of the nine quinoa genotypes.

Varieties	Origin	Grain color	Accessions under development	Origin	Grain color
Amarilla Marangani	Peru	Orange	QS14 (selected from crosses with Blanca)	Denmark	Cream
Amarilla Sacaca	Peru	Yellow			
Blanca de Junin	Peru	Cream	QS16 (selected from crosses with Rosada)	Denmark	Cream
Kancolla	Peru	Cream			
Salcedo INIA	Peru	Cream	QS17-2 (selected from crosses with ancient Pasankalla)	Peru	Red
Rosada de Huancayo	Peru	Cream			

The area of each plot was 10.8 m^2, 2.4 m in width (4 lines 60 cm apart) and 4.5 m in length (one plant per hill distanced at 15cm between hills). Quinoa was drilled in lines on 2nd of December 2014 and on 28th of November 2015. Plots were kept free of weeds through hoeing four times. Maize was the preceding summer crop in both seasons. Sprinkler irrigation was the irrigation system. The field was finely prepared and calcium super phosphate (15.5% P_2O_5) was applied during soil preparation at the rate of 476 Kg per ha. Ammonium nitrate (33.5%) was applied at the rate of 214.2 Kg N/ha in five split equal doses, the first after two weeks from planting date and the other doses every two weeks. **Table 2** shows Meteorological information data of Ismailia governorate (October-May) in the two growing seasons.

Mechanical and chemical analyses of the soil (0 - 30 cm) were done by Water, Soil and Environment Research Institute, ARC (**Table 3**) according to Jackson [17] and Chapman and Pratt [18]. The experimental soil had 12.65 percent clay, 2.40 percent silt and 84.95 percent sand, and loamy sand texture.

Table 2. Meteorological information data of Ismailia governorate (October-May) in 2014/2015 and 2015/2016 growing seasons.

Season / Months	2014/2015				2015/2016			
	Temperature (˚C)		Relative humidity (%)	Rain (mm/day)	Temperature (˚C)		Relative humidity (%)	Rain (mm/day)
	Max	Min			Max	Min		
October	30.57	17.94	61.92	0.99	31.04	19.62	58.03	0.30
November	25.71	14.21	58.13	1.17	25.44	14.69	63.63	0.44
December	17.88	7.61	68.70	0.52	19.78	9.67	65.32	0.25
January	18.40	7.40	54.68	0.65	17.67	6.77	63.74	0.43
February	19.89	7.96	50.92	0.28	23.54	9.43	53.02	0.08
March	25.08	11.16	50.81	0.13	25.02	11.19	48.28	0.09
April	27.40	11.57	45.77	0.53	32.32	15.19	37.71	0.11
May	32.90	16.82	40.75	0.03	33.26	17.26	38.48	0.00

NASA website.

Table 3. Chemical analysis of the experimental soil before growing quinoa genotypes.

Chemical analysis	Growing season	
	2014	2015
pH	7.75	7.89
N (ppm)	19.10	19.25
P (ppm)	2.55	2.72
K (ppm)	39.07	39.28
Organic matter	0.47	0.51

The studied traits

Growth duration

Growth duration was recorded by estimating number of days from sowing to maturity.

Grain yield and its attributes

The following traits were measured on ten guarded plants from each plot at harvest; plant height (cm), number of branches per plant, 1000-grain weight and grain yield per plant. Grain yield per ha (ton) was recorded on the basis of plot area by harvesting all plants of each plot and converted to yield per ha.

Chemical analysis

Grain samples from each replicate of best grain yield treatment were taken in the two growing seasons after harvesting and mixed together, left for air drying to 15% moisture content then sent to laboratory for preliminarily chemical analysis. Grain protein and saponins contents were analyzed by the Regional Center for Food & Feed, A.R.C., Giza, Egypt according to A.O.A.C. [19].

Economic evaluation

Production costs and total income in this study were calculated based on averages of collected data from four locations of Ismailia, Sharkia, Behira and Fayoum governorates to standardized the net return for newquinoa farmers compared with wheat in 2015/2016 season [20].

Statistical analysis:

Data were analyzed using ANOVA in Randomized Complete Block Design with three replications. MSTAT-C [21] was used for statistical computations.

3. Results and Discussion

1) Growth duration

As a result of different agro-ecological extremes (soils, rainfall, temperatures, and altitude) within the areas of origin, quinoa shows a broad genetic diversity and can be divided into five ecotypes highly adapted to specific environments, being tolerant against various abiotic stress factors (frost, drought, and salinity) [22]. Results in **Figure 1** show that the QS17-2 accession stays only from 115 to 120 days in the field and treated as short duration accession, while, varieties of Blanca de Junin, Salcedo INIA and Rosada de Huancayo, as well as, accessions of QS14 and QS16 were moderate in their growth duration (140 days in the first season and 134 days in the second one).

Moreover, varieties of Amarilla Marangani, Amarilla Sacaca recorded up to 160 days in the first season and 157 days in the second one which treated as long duration genotypes. It seems that Egyptian climatic and edaphic factors (**Table 2** and **Table 3**) had a major role in growth duration of the studied quinoa genotypes that is a predominantly self-pollinating species indicating considerable variation exists among the genotypes for many of the desired characters. It seems that temperature, relative humidity and rain played a major role in maturity stage of quinoa where the tested quinoa genotypes reached maturity stage

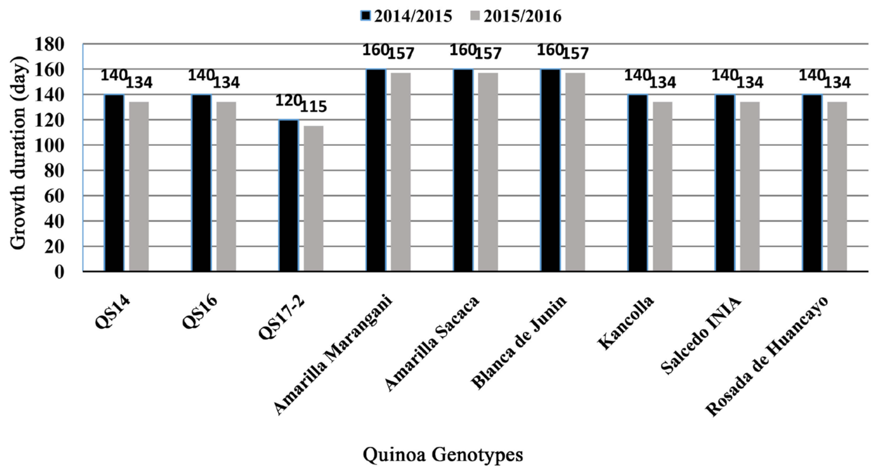

Figure 1. Growth duration of the tested quinoa genotypes in both seasons.

earlier in the second season than the first one. Certainly, the sensitivity against photoperiod is the most important factor in creating new varieties adapted to higher latitudes [23].

2) Grain yield and its attributes

Results in **Table 4** reveal that Amarilla Sacaca variety and QS16 accession were the tallest in the first and second seasons, respectively, whereas Salcedo INIA variety had the shortest ones in the both seasons. These results may be primarily attributed to genetic differences among the genotypes had a major role to interact differently with day length which reflected on their internode elongation under sandy soil conditions. It seems that genetic makeup of quinoa genotypes Amarilla Sacaca and QS16 translated into alteration of plant height growth rate for helping these plants to reach enough light compared with the other genotypes. These results are in the same context with those obtained by Maliro*et al.* [24] who revealed that Bio-Bio variety grew to a height of 66 cm, followed by Brightest Brilliant Rainbow (64 cm).

The maximum number of branches per plant was obtained by Amarilla Sacaca variety and QS16 accession in the first and second seasons, respectively, while Kancolla variety had the lowest value of this trait in both seasons. So, it is likely that genetic makeup of quinoa genotypes Amarilla Sacaca and QS16 sustained growth of new branches development during pollination process compared to the other genotypes under sandy soil conditions.

Also, data in **Table 4** show that the highest values of 1000-grain weight were recorded by QS17-2 accession, while the lowest values were obtained by Blanca de Junin variety compared with the other genotypes in the both seasons. These results probably due to genetic differences among the studied genotypes differed in assimilates and it's partitioning to the panicle. It seems that QS17-2 accession was more effective in translocating photosynthates from leaves and stalks to the developing panicle compared with the other genotypes under sandy soil conditions.

Table 4. Grain yield and its attributes of some quinoa genotypes under sandy soil conditions in the two growing seasons.

Trait / Genotype	Plant height (cm)	Number of branches/plant	1000-grain weight (g)	Grain yield/plant (g)	Grain yield/ha (ton)
			2014/2015 season		
QS14	111_{c}	19_{bc}	3.0_{e}	17_{de}	1.632_{bc}
QS16	131_{ab}	22_{ab}	2.7_{fg}	18_{cde}	1.661_{bc}
QS17-2	97_{d}	16_{cd}	4.5_{a}	26_{ab}	2.100_{ab}
Amarilla Marangani	130_{ab}	20_{bc}	3.5_{d}	26_{ab}	2.114_{ab}
Amarilla Sacaca	135_{a}	25_{a}	3.7_{c}	27_{a}	2.228_{a}
Blanca de Junin	127_{b}	19_{bc}	2.5_{g}	13_{e}	1.070_{d}
Kancolla	77_{f}	12_{d}	4.1_{b}	23_{abc}	2.083_{ab}
Salcedo INIA	76_{f}	14_{d}	3.9_{bc}	21_{bcd}	1.442_{c}
Rosada de Huancayo	90_{e}	17_{cd}	2.8_{ef}	16_{de}	1.297_{cd}
			2015/2016 season		
QS14	123_{bc}	21_{ab}	3.4_{d}	20_{cd}	1.342_{e}
QS16	155_{a}	24_{a}	2.8_{e}	24_{bc}	1.926_{cd}
QS17-2	103_{c}	20_{ab}	4.7_{a}	28_{ab}	2.680_{ab}
Amarilla Marangani	145_{ab}	20_{ab}	3.7_{c}	28_{abc}	2.404_{ab}
Amarilla Sacaca	146_{ab}	20_{ab}	3.8_{c}	31_{a}	2.747_{a}
Blanca de Junin	123_{bc}	23_{ab}	2.6_{e}	17_{d}	1.163_{e}
Kancolla	118_{bc}	16_{b}	4.3_{b}	26_{abc}	2.253_{bc}
Salcedo INIA	97_{c}	18_{ab}	4.1_{b}	22_{bcd}	1.638_{de}
Rosada de Huancayo	107_{c}	18_{ab}	2.9_{e}	21_{cd}	1.527_{de}

In case of grain yields per plant and per ha, the results indicate clearly that the highest values of these traits were recorded by the quinoa genotypes Amarilla Sacaca, Amarilla Marangani, QS17-2 and Kancolla, while Blanca de Junin variety had the lowest values of these traits in the both seasons. These results may be attributed to yield potential of the studied quinoa genotypes related to the genetic differences that reflected on differ in their competitive abilities for assimilate distribution between organs of quinoa plant. So, it may be possible that genetic potential of the quinoa genotypes Amarilla Sacaca, Amarilla Marangani, QS17-2 and Kancolla translated into suitable canopy architecture that induced a deeper root system and a faster horizontal root development, indicting efficient use of all nutrients by all parts of these genotypes compared to the other genotypes.

Accordingly, these results reveal that quinoa proved success in desert lands with suitable grain yield. Similar results were obtained by Zuniga *et al.* [25] who evaluated the productivity of Amarilla Sacaca and Amarilla Marangani varieties and they found that the both varieties produced more than 2.3 ton/ha with the superiorty to Amarilla Sacaca variety. Also, Huaringa [26] tested ten varieties of quinoa (Blanca de Hualhuas, Rosada de Huancayo, INIA 415-Pasankalla, Kancolla, Illpa - INIA, Blanca de Juli, Salcedo - INIA, INIA 420-NegraCollana, INIA 431 - Altiplano and Amarilla de Marangani). He mentioned that the superiority of Amarilla de Marangani variety over the rest of varieties with yield of 3.5 ton/ha. Moreover, these results are in accordance with those obtained by Shams [27].

3) Chemical composition

Data in **Table 5** reveal that the maximum protein content in quinoa grains were recorded with QS17-2 (13.77% in the first season and 13.43% in the second one), QS16 (12.88% in the first season and 12.76% in the second one) and Rosada de Huancayo (12.38% in the first season and 12.22% in the second one), meanwhile the lowest protein contend was recorded by Blanca de Junin variety (10.83% in the first season and 10.67% in the second one). These findings are parallel with those obtained by Huaringa [26] who showed that the protein content in Salcedo INIA was higher than those in Kancolla and Amarilla Marangani, respectively. It is known that the nutritional properties, especially the high protein contents or rather the well-balanced composition of proteogenic amino acids, are two of the most promising features of quinoa [28].

Table 5. Protein and saponins in grains of some quinoa genotypes.

Trait / Genotype	Protein (%)	Total Saponins (%)
	2014/2015 season	
QS14	11.37_f	0.184_b
QS16	12.88_b	0.222_a
QS17-2	13.77_a	0.132_d
Amarilla Marangani	10.96_g	0.129_d
Amarilla Sacaca	12.02_{de}	0.164_c
Blanca de Junin	10.83_g	0.093_e
Kancolla	11.86_e	0.130_d
Salcedo INIA	12.26_{cd}	0.076_f
Rosada de Huancayo	12.38_c	0.143_d
	2015/2016 season	
QS14	11.03_f	0.156_b
QS16	12.76_b	0.214_a
QS17-2	13.43_a	0.120_c
Amarilla Marangani	10.82_{fg}	0.119_c
Amarilla Sacaca	11.86_d	0.154_b
Blanca de Junin	10.67_g	0.085_d
Kancolla	11.60_e	0.120_c
Salcedo INIA	11.96_d	0.064_e
Rosada de Huancayo	12.22_c	0.133_c

On the other hand, the saponins content values in quinoa grains were recorded for Salcedo INIA (0.076% in the first season and 0.064% in the second one), Blanca de Junin (0.093% in the first season and 0.085% in the second one), Amarilla Marangani (0.129% in the first season and 0.119% in the second one), Kancolla (0.130% in the first season and 0.120% in the second one), QS17-2 (0.132% in the first season and 0.120% in the second one), Rosada de Huancayo (0.143% in the first season and 0.133% in the second one), Amarilla Sacaca (0.164% in the first season and 0.154% in the second one), QS14 (0.184% in the first season and 0.156% in the second one) and QS16 (0.222% in the first season and 0.214% in the second one), respectively. These results could be attributed to limited supply of water affected negatively the formation of saponins contained in quinoa seeds during the growth and development stages; and this effect was increased or decreased according to quinoa genotype that grown under sandy soil conditions, therefore deficit irrigation can be used as sustainable practice to reduce saponin levels in quinoa seeds [29]. It seems that quinoa genotypes QS17-2, QS16 and Rosada de Huancayo regulate the production of bioactive compounds more than the rest genotypes, influencing its nutritional and industrial values.

4) Economic evaluation

Data in **Table 6** indicate clearly that production costs for quinoa and wheat did not exceed the one thousand US$/ha including land rent.

Amarilla Sacaca variety gave the highest net return of US$ 1509 in local market followed by QS17-2 accession and Amarilla Marangani variety, while wheat gave the lowest total income and net return (**Table 7**).

Table 6. Average costs of production per hectare for quinoa compared with wheatcrop (US$*/ha).

Item with Description	Quinoa	Wheat
Land preparation (Plowingtwo times)	24	12
Seeds cost (10 Kg of quinoa and 71 kg of wheat)	10	19
Sowing (6 workers for Quinoa and 2 for wheat)**	30	10
Fertilizers (30 kg P_2O_5 and 100 Kg N for both)	135	135
Fertilization and Irrigation (Per season)	40	60
Weeding (Hoeing two times for quinoa)	120	-
Harvesting (19 workers for quinoa and 24 for wheat)	95	120
Thrashing (Thrasher rental and workers)	180	180
Sub-total without land rent	634	536
Land rent (Per hectare)	357	357
Total cost with land rent	991	893

*All costs at the exchange rate of (1 US$ = 20 EGP). **Workers wages based on (5 US$ for worker/day).

Table 7. Economic evaluation of new quinoa genotypes under sandy soil conditions compared with wheat crop.

Trait / Genotype	Average grain yield (ton/ha)	Evaluation based on Egyptian prices		Evaluation based on International prices	
		Total income* (US$/ha)	Net return (US$/ha)	Total income* (US$/ha)	Net return (US$/ha)
QS14	1.5	1500	509	1751	760
QS16	1.8	1800	809	2101	1110
QS17-2	2.4	2400	1409	2801	1810
Amarilla Marangani	2.3	2300	1309	2684	1693
Amarilla Sacaca	2.5	2500	1509	2918	1927
Blanca de Junin	1.2	1200	209	1400	409
Kancolla	2.2	2200	1209	2567	1576
Salcedo INIA	1.5	1500	509	1751	760
Rosada de Huancayo	1.4	1400	409	1634	643
Wheat	-	1174	281	-	-
Wheat grains	7.1	994	-	-	-
Wheat straw	6	180	-	-	-

*Price of quinoa grains (US$ 1167/ton), source FAOSt at data, 2017. **Farm prices in Egypt (quinoa grains = US$ 1000/ton) and (wheat grains = US$ 140/ton & wheat straw = US$ 30/ton), source (Shams, 2016).

The results also gave a clear indicator of the lower farm prices of quinoa grains in Egypt (1 US$/Kg) compared to international farm prices (from 1.167 up to 2.773US$ /Kg) [30], which gives a comparative advantage to Egypt in the MENA region for agricultural investment especially in growing quinoa crop for exportation which increase the net return at least by 28% with possibility of more increases with adding values of removing saponins, grading, sorting and packaging. These results are in agreement with those recorded by Jacobsen [12] who reported that the economic result for the farmer depends on the yield and the price to be achieved for the crop and add that any improved result will be obtained with either an increased yield or a higher price. Also, Shams [16] found that quinoa can be grown under harsh conditions of sandy soils, arid environment.

4. Conclusion

Quinoa crop is recommended to replenish part of cereals gap where it can grow successfully and competitively with high profitability to the small-scale farmers under sandy soil conditions. The nutritional composition of quinoa varied among genotypes due to strong genetic variability in addition to environmental differences; this diversity can be the basis for possible adaptations in the fight against cereal gap. QS17-2 is new red quinoa accession for more selection and development to produce a new competitor colored and short duration quinoa variety. The economic evaluation gave a clear indicator of the lower farm prices of quinoa grains in Egypt, which gives a comparative advantage to Egypt in the MENA region for quinoa exportation.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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