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Possibility of introducing quinoa to the Egyptian's cropping structure by intercropping with onion crop

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Abstract: This study proposes the introduction of quinoa into the cropping structure in sandy soil, through intercropping with onion, as a sustainable solution to mitigate climate change effects. The study was conducted during the two growing seasons 2021/ 2022 and 2022/2023 in Ismailia Agricultural Research Station, ARC, Ismailia governorate, Egypt to investigate the effect of 3 planting dates (4WBT: 4 weeks before transplant onion, 2WBT: 2 weeks before transplant onion, and AST: at the same time of transplant onion) and 3 plant spacing of quinoa (10, 20 and 30 cm) intercropped with onion on the productivity of the two crops, quality traits in quinoa, and the farm's income. Results indicated that planting quinoa 2WBT at 10 cm had the highest grain yield of quinoa, while planting date at 4WBT had the maximum values of quinoa quality traits by planting quinoa at 30 cm for grain protein content and 10 cm for saponin. In addition, the highest yield of the onion produced by planting quinoa 4 WBT at spacing of 30 cm. The highest values of LER (1.46 and 1.42) and total and net income produced by intercropping quinoa at planting date 2 WBT and 10 cm spacing in first and second season, respectively. Despite onion price fluctuations in both seasons caused by climate change (rainfall), and impacting output, intercropping quinoa with onion produced a higher and more stable financial return than sole onion cultivation in either season. Accordingly, it can be introducing quinoa into cropping structure in sandy and marginal soils by intercropping quinoa 2 weeks before transplanting onion at a plant spacing of 10 cm to increase land equivalent ratio and net income for Egyptian farmers than onion sole cultivation.

Keywords: Quinoa, Onion**,** planting dates, plant spacing, quality traits, transplanting and yield, LER, income

INTRODUCTION

The current climate changes pose a significant threat to the productivity of many crops, *i.e.* onion. This can lead to a sharp decline in the productivity of most main food crops, as well as an increase in their water consumption and soil degradation. To mitigate these risks, it is important to develop the Egyptian cropping structure in sandy soil by introducing new crops such as quinoa. Quinoa is a drought-resistant crop that can withstand extreme weather conditions, making it an ideal choice for regions facing the adverse impacts of climate change (Jacobsen *et al*., 2003). Thus, this cropping system presents a promising alternative for farmers to sustainably manage their land and adapt to the changing climate. By integrating it into the cropping structure in marginal areas or poor soil quality, farmers can diversify their products, extend markets, improve human and animal diets, and create new industries. This presents an opportunity for new jobs, a means to cultivate reclaimed land, and the creation of new agricultural zones (Doweidar and Kamel, 2011). It is possible to introduce quinoa to the cropping structure through mixed cultivation. Intercropping quinoa helps to enrich biodiversity and soil health, better utilization of environmental resources, particularly water and improve farm income (Devkota Wasti and Nangia, 2021). The quinoa plants have a positive allelopathic effect on the content of primary and secondary metabolites of barley and onion (Valencia *et al*., 2017). Intercrop treatments (fescue/clover and clover/medic) increased quinoa seed protein without affecting quinoa yield (Walters *et al*., 2016). The possibility of yield improvement in intercropping systems depends on various factors such as planting date, cultivar, plant density, planting pattern, and contribution of each species. Planting dates affected the growth and productivity of quinoa owing to the differences in temperature, rainfall and solar radiation over the year (Hirich *et al*., 2014 and Mahmoud, 2017). In the same regard, Bhargava *et al.* (2007) showed that highest yield was obtained at 25 cm spacing for15 November sowing date in first season, and at 20 cm spacing for 30 November sowing date in second season. While late sowing date 15 December gave the lowest yield for all the spacing. Under Toshka conditions, the date of 1st November is good time to quinoa in order to explore its yield potential compared to 1st October (Awadalla and Morsy, 2017). Shoman (2018) found that sowing date in first December had the highest values for all studied traits as compared with sowing date in first October, and first November, at EL-Kharga Oasis. (Hammad *et al*., 2021) the highest seed yield/fed obtained on 10-October with density 84.000 plant/fed, under the climatic prevailing of Aswan Governorate. Planting density is one of the most important management decisions that control the competition between plants in mixed planting systems (Cha *et al*., 2016). Variances in planting densities are caused by variation in soil fertility and soil characteristics (Maliro *et al*., 2017). In the same trend, (Wali *et al*., 2022) stated that decreasing plant spacing of quinoa from 30 cm to 15 cm boosted biological yield, seed yield, straw yield, 1000-seed weight, and harvest index considerably. In mixed cultivation, millet and quinoa showed substantial effects on each other when intercropped at varying planting densities due to differences in architectural and physiological properties (Vahidi *et al*., 2021). Quinoa (*Chenopodium quinoa* Willd.) belonged to Amaranthaceae family. It's considered a pseudo cereal

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that produces a grain-like seed, which can be sold as a whole grain or used in bread, soups or other uses. Quinoa is listed as the plant species that can provide food security in the twenty-first century, because of its nutritious properties and significant resilience to abiotic stresses (FAO, 2011). It is a food crop recently introduce in Egyptian crop structure, because of its grains has high nutritional value (Abdelhamid, 2016), especially protein content, twice as much as common cereal grains (Bhathal and Kaur, 2018). Quinoa could be used in bread in combination or substitution of wheat and other seed products (Shams and Galal, 2014). Quinoa can be used to produce gluten-free cereal-based products and contains all nine essential amino acids (Escuredo *et al*., 2014; Abdellatif, 2018). Quinoa can be used as an alternative cash crop for soil and water unsuitable for traditional crops in arid and semiarid areas (Choukr-Allah *et al*., 2016; Eisa *et al*., 2017), and high adaptation to climate change (Bazile *et al.,* 2016). In Egypt, several studies were undertaken on quinoa to reduce the food gap as new crop. However, no work has been conducted so far to suggest the possibility of introducing quinoa to cropping structure by intercropping quinoa with main crops to increase land and water utilization and income, under climatic change. Therefore, this study was conducted to find out the best planting dates and spacing of quinoa intercropped with onion to produce the highest productivity of both crops, quality traits of quinoa, and the farm's income.

MATERIALS AND METHODS

Description of experimental site: Field experimental was conducted during the two growing seasons 2021/ 2022 and 2022/2023 in the Experimental Farm of Agricultural Research Station in Ismailia, ARC, Egypt. The experimental soil was sandy in texture. Physical properties and chemical analysis of the experimental soil sites (0-30 cm depth) are presented in Table (1) according to standard methods described by Piper (1950) and Jackson (1973). The following website: https://power.larc.nasa.gov/data-access-viewer/site was used to obtain averaged monthly data on the weather at the experimental site during both growing seasons, was presented in Table (2).

Table 1: Some physical and chemical analysis of the experimental soil in 2021/2022 and 2022/2023 seasons

Season	Physical analysis				Chemical properties			
	Sand%	Silt%	Clay%	Texture	pH	EC dsm^{-1}	OM %	Ca CO_3 %
2021/22	94.10	2.40	3.50	Sandy	7.85	0.95	0.43	1.95
2022/23	92.15	3.50	4.35		7.90	1.05	0.52	2.13
Season	Soluble cations (mmolic l^{-1})				Soluble anions (mmolic l^{-1})			
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl-	SO_4^{2-}
2021/22	4.30	1.85	2.45	0.95	-	2.20	2.60	4.75
2022/23	4.35	1.95	2.50	1.63	-	2.30	2.75	5.38

Table 2: Average monthly weather data at the experimental site in 2021/2022 and 2022/2023 seasons

	T_{Max} (°C)	T_{Min} (°C)	RH (%)	Rain (mm/day)	WS (m/s)	T_{Max} (°C)	T_{Min} (°C)	RH (%)	Rain (mm/day)	WS (m/s)
	2021/2022 season					2022/2023 season				
Nov.	27.38	15.93	62.30	0.38	2.34	26.30	14.45	64.29	0.19	2.31
Dec.	19.91	10.14	64.80	0.60	2.76	21.58	11.79	68.62	0.23	2.18
Jan.	16.76	6.46	67.12	1.50	2.61	20.63	9.36	65.83	0.23	2.23
Feb.	19.33	7.37	67.67	0.45	2.59	19.06	7.38	64.81	0.10	2.76
Mar.	20.20	7.81	61.94	0.65	3.12	25.79	12.27	50.08	0.32	3.03
Apr.	29.47	13.65	51.84	0.00	3.22	28.88	13.74	48.38	0.14	3.22
May	31.90	16.55	48.41	0.00	3.30	32.10	17.15	50.28	0.46	3.38

TMax= maximum temperature, TMin= minimum temperature, RH =Relative humidity, WS = wind speed

Experimental design and treatments: A randomized complete block design (RCBD) with three replicates was used for each planting dates as an individual experimental. Then, all three planting dates experimental were combined as split-plot design. Experimental plots area was 12 m^2 (3 m×4 m), with 5 ridges (80 cm width). The experimental factors were 3 planting dates of quinoa (4WBT: four weeks before transplanting onion, 2WBT: two weeks before transplanting onion, and AST: at the same time as onion cultivation) and three hill spacing of quinoa (10, 20, and 30 cm) which were allotted in the main and sub-plot, respectively. After 3 weeks from sowing date, the quinoa seedlings were thinned to two plants per hill. The recommended sole planting of onion and quinoa was used to calculate competitive relationships.

Experimental field practices and Plant materials: Peanut as preceding crop and sprinkler irrigation system was used in this study. The experimental field was ploughed and then harrowed and division to obtain optimum seedbed before cultivation. Three rows of onion (75% of its sole onion) and one row of quinoa per the ridge were planted. The distance between onion rows was 15 cm, and between quinoa and onion was 20cm, while the intra rows spacing were 10 cm for onion and 10, 20, and 30 cm for quinoa, which is equal to 75, 37.5 and 25 % plant density of its sole quinoa, as illustrated in Figure (1). Quinoa cv. Misr 1 was sown on November 1st, 15th and December 1st and harvested on April 1st, 15th and 28th, respectively, in both growing seasons. While onion (cv. Giza 20) transplanting was done on 1st December and harvested on 28th and 27th April in first and second season, respectively. Both onion and quinoa seeds were obtained from Field Crop Research Institute, ARC. Phosphorus fertilizer was added at a level of 300 kg/fed as mono calcium super phosphate (15.5% P_2O_5) during soil preparation. Potassium fertilizer was added once at a rate of 50 kg/fad as potassium sulphate (48% K_2O) at during soil preparations. Nitrogen was applied as ammonium nitrate (33.5% N) at a rate 60 and 80 kg N/fed for intercropping and sole planting of onion in five equal doses. For quinoa, 100 kg N/fed was applied for sole planting, whereas intercropping planting of quinoa received 75, 37.5 and 25 kg N/fed according to the plant density of quinoa. Which was applied as following, 20 kg/fad as boosting dose during quinoa cultivation, and after 3 weeks the rest amount was applied in 4 equal doses every week. Plots were kept free of weeds through hand hoeing twice.

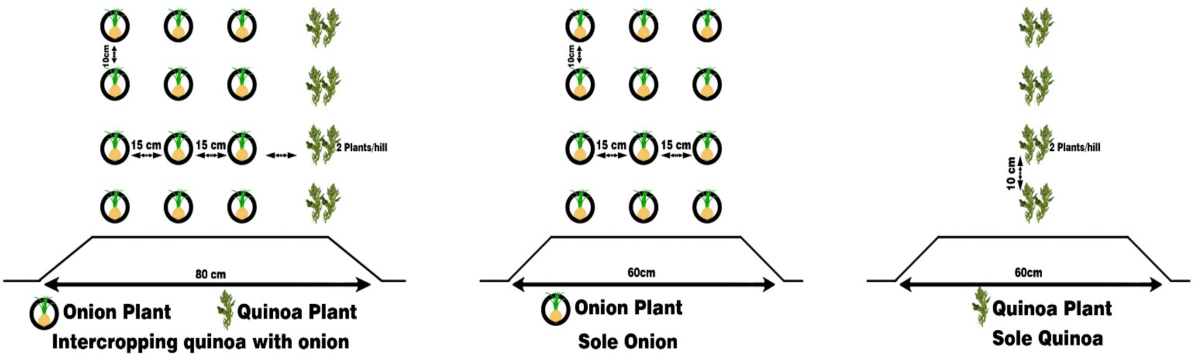

Figure 1: Schematic diagram of different planting systems of onion and quinoa

Data recorded: At harvest, ten plants of each crop were randomly taken from the inner ridges of sub-plot to estimate the following traits for:

1- Onion: Plant height (cm) is measured from the base of the disc stem to the top of the leaves, number of leaves/plants, bulb diameter (cm) and average bulb weight (g). In addition, onion yield /fed determined based on sub-plot and then converted to ton/ fed.

2- Quinoa: Plant height (cm) is measured from the soil surface to the top of the panicle, number of panicles/plants, grain weight /plant (g) and 1000-grain weight (g). In addition, grain yield/ fed (kg) was determined based on the sub-plot yield and then converted to kg/fed. Also, protein content % calculated by determined total N % according to AOAC (2005), while saponin % was estimated according to Jacobsen et al. (2000).

Competitive relationships: Generally, various competitive indices including land equivalent ratio (LER), and aggressivity were calculated based on sole planting of each crop.

Land equivalent ratio (LER): known as the ratio of the land required for sole planting versus intercropping at a similar management level to achieve an equal yield (Willey, 1979). It is calculated as follows: LER = Yab /Yaa + Yba /Ybb where Yaa and Yab= sole and intercrop yield of crop a (Onion), Ybb and Yba = sole and intercropped yield of crop b (Quinoa).

Aggressivity (A): is index of how much one crop's relative yield gain exceeds that of the other in an intercropping system (Mc-Gilchrist, 1965) and was computed as follows:

Aab =[Yab / (Yaa × Zab)]–[Yba / (Ybb × Zba)]

Aba =[Yba / (Ybb × Zba)]–[Yab / (Yaa × Zab)] where Zab and Zba were the sown proportions of onion and quinoa, respectively.

Economic evaluation: It was calculated by determining the net return of intercropping culture as compared to recommended sole planting of onion crop. Gross income = Price of onion yield + Price of quinoa yield (LE). The average onion price was according to market price, while FAO (2022) price of quinoa was used. The onion price was 1.5 and 10.0 L.E/ kg of bulbs, meanwhile quinoa price was 27.7 and 63.0 L.E /kg of grains, in first and second season, respectively. Net return /fed = Gross income – Production costs (fixed costs of onion + variable costs of quinoa).

Statistical Analysis: Statistical analysis was performed using analysis of variance technique of MSTATC statistical package (Freed, 1991). Data were analyzed according to Gomez and Gomez (1984). Means of treatments were compared using the least significant differences (LSD) developed by Waller and Duncan (1969) at 5% level. The mean values of onion and quinoa plants were utilized for estimation of correlation coefficient as per the method suggested by Johnson et al, (1955).

RESULTS AND DISCUSSION

Onion traits response to planting dates of quinoa: All studied traits of onion significantly affected by planting dates of quinoa in both seasons, as shown in Table (3). Planted quinoa 4 weeks before transplant onion had the highest values of No. of leaves/plant, bulb diameter, bulb weight and onion yield/fed, while plant height behaved the opposite trend in both seasons. The first sowing date of quinoa, quinoa sowing 4 weeks before transplanting onion (4 WBT), significantly increased onion yield by 6.3 and 10.5 % in 2021/2022 season and 8.6 and 13.8% in 2022/2023 season compared to the planting date at 2 weeks before transplanting onion (2 WBT) and sowing quinoa at same time of transplanting onion (AST), respectively. These results may be attributed to the early quinoa planting date in first November (4WBT of onion) allowed the lower competition of quinoa with onion plants for light compared to other sowing dates, which had the lowest plant height of quinoa as shown in Table (3). Another interpretation, the earlier harvesting date of quinoa (one month before onion), when quinoa was planted at 4 WBT, gives a good chance for onion to grow, develop, and increase its yield. Intercropping advantages are usually better when the sowing date of the component crops vary widely than when the crops sowing date are close together (Yahuza 2011). These results were in line with El-Mehy *et al.* (2023) who found that the long overlap duration of maize intercropping with common beans significantly decreased common beans and maize yields compared with the short overlap duration.

Onion traits response to plant spacing of quinoa: Quinoa plant spacing significantly affected plant height, number of leaves/plant, bulb diameter, bulb weight of onion plants and onion yield/fed in both seasons, except number of leaves/plant and bulb diameter were significant in the first season, as shown in Table (4). The highest value of onion plant height was produced with quinoa planted at a distance of 10 cm between plants, while the shortest plants were obtained with wider spacing at 30 cm. This result indicates that increasing plant density per unit area increased shading effect and inter-competition between quinoa and onion crops, which increased onion plant height for searching on sunlight. These findings are consistent with Sheha *et al.* (2022) reported that the highest plant density of faba bean had the greatest shadow effect on onion plants, which produce the tallest onion plants compared with low plant density. However, a wider quinoa spacing at 30 cm had the highest values of yield and yield components of onion. Intercropped quinoa at 30 cm increase bulb yield/fed compared to plant spacing 10 and 20 cm by 11.7 and 6.9% in first season and 13.0 and 6.7% in second once, respectively. This result may be due to reduce plant density of quinoa per unit area reduce inter-specific competition between combination crops. These results agree with those of Sheha *et al.* (2022) except for plant height, the mean value of onion yield and its components decreased gradually as faba bean density increased. The highest yield of guar seeds was obtained by intercropped quinoa at 20 cm plant spacing between hills, while the lowest yield of guar seeds was obtained from the plant spacing 10 cm (Araghian *et al.,* 2021).

Onion traits response to interaction effect: Significant effect of quinoa planting dates and spacing on bulb diameter, bulb weight and onion yield/fed in both seasons as presented in Table (5).

Results clear that planting quinoa 4 weeks before transplant onion (4 WBT) at 30 cm plant spacing gave the highest values of all the previously mentioned traits. While the lowest values of these traits were obtained by planting quinoa at the same time of transplant onion plants (AST) and the narrowest spacing (10 cm). This means harvesting quinoa one-month earlier onion and increasing spacing of quinoa from 10 cm up to 30 cm increased bulb diameter, bulb weight, and yield/fed of onion. These results may be due to the reduced interspecific competition for sunlight, water and nutrients as quinoa plant population increase, especially when quinoa sowing at the same time of onion. Temporal integration among intercropped crops was due to variations in planting and harvesting dates (Dong *et al.,* 2018). Similar results were obtained by Sheha *et al.* (2022) who found that early planting date of onion with the lowest faba bean plant density was the best treatment for yield (ton/fed) and average bulb weight (g) of onion.

Quinoa traits response to planting dates: The obtained results in Table (6) clearly show that the third planting date of quinoa, AST (at the same time of onion cultivation), significantly increased plant height in both growing seasons, whereas the lowest plant heights 87.34 and 79.40 cm were produced with 4WBT (4 weeks before transplanting onion) in the 2021/22 and 2022/23 season, respectively. These results can be explained by synchronizing quinoa with onions increased competition among the two crops on light interception, which increased the stem elongation of quinoa plants, compared the other sowing date. This result is in accordance with those obtained by Mourad and El-Mehy (2021) simultaneous shadowing of intercrops can enhance the proportion of invisible radiation, which has an elongating effect on plants. As for yield of quinoa and its components, results in Table (6) show that the effect of planting dates on number of panicles/plants, grain weight/plant, and grain yield /fed, was significant in the two growing seasons, except 1000-grain weight. The second planting date at 2WBT (2 week before transplanting onion) had the highest values for all studied traits of yield and its components. Sowing quinoa at 2WBT increased grain yield per plant by 10.6 and 17.8% in first season, and by 8.6 and 24.0% in second season. Likewise, grain yield per feddan. increased by 13.7 and 24.1% in 2021/22 season and 12.4 and 17.0 % in 2022/23 season compared to 4WBT and AST, respectively. The results confirm that planting quinoa in mid-November was superior to other planting dates and met the environmental needs of the plant, followed by early November.

Table 3: Response of onion traits to quinoa planting dates in 2021/2022 and 2022/2023 seasons

Planting date (A)	Plant height (cm)	No. of leaves/plant	Bulb diameter (cm)	Bulb weight (g)	yield/fed (ton)
		2021/2022 season			
4WBT (1st Nov.)	52.17	6.81	5.17	63.36	8.74
2WBT (15th Nov.)	57.39	6.23	4.84	58.80	8.22
AST (1st Oct.)	61.11	5.86	4.59	56.10	7.91
LSD at 5%	3.23	0.35	0.17	4.15	0.28
		2022/2023 season			
4WBT (1st Nov.)	49.28	6.21	4.72	59.94	7.44
2WBT (15th Nov.)	53.61	5.78	4.33	55.12	6.85
AST ((1st Oct.)	59.28	5.50	4.12	52.66	6.54
LSD at 5%	2.81	0.42	0.45	5.7	0.49

4WBT and 2WBT: planting quinoa 4 and 2 weeks before transplant onion, AST: planting quinoa at the time of transplant onion.

Table 4: Response of onion traits to quinoa plant spacing in 2021/2022 and 2022/2023 seasons

Plant spacing (B)	Plant height (cm)	No. of leaves/plant	Bulb diameter (cm)	Bulb weight (g)	yield/fed (ton)
		2021/2022 season			
10 cm	61.33	6.01	4.64	55.98	7.87
20 cm	56.61	6.37	4.81	58.98	8.22
30 cm	52.72	6.52	5.14	63.30	8.79
LSD at 5%	1.85	0.34	0.12	5.12	0.27
		2022/2023 season			
10 cm	57.17	5.30	4.16	52.57	6.53
20 cm	54.11	5.88	4.39	55.71	6.92
30 cm	50.89	6.31	4.63	59.44	7.38
LSD at 5%	2.63	N.S	N.S	2.35	0.18

N.S: Not significant

Table 5: Response of onion traits to interaction effect of planting dates and spacing of quinoa in 2021/2022 and 2022/2023 seasons

Planting date (A)	Spacing (B)	Plant height (cm)	No. of leaves/plant	Bulb diameter (cm)	Bulb weight (g)	yield/fed (ton)
			2021/2022 season			
4WBT	10cm	54.33	6.53	4.90	59.37	8.23
(1st Nov.)	20cm	51.67	6.90	5.00	62.43	8.59
	30cm	50.50	6.99	5.60	68.27	9.41
2WBT	10cm	63.83	5.93	4.60	55.57	7.82
(15th Nov.)	20cm	57.50	6.30	4.83	58.50	8.18
	30cm	50.83	6.47	5.10	62.33	8.67
AST	10cm	65.83	5.57	4.43	53.00	7.55
((1st Oct.)	20cm	60.67	5.90	4.60	56.00	7.88
	30cm	56.83	6.10	4.73	59.30	8.29
LSD at 5%		N.S	N.S	0.49	6.68	0.35
			2022/2023 season			
4WBT	10cm	51.17	5.53	4.37	55.40	6.88
(1st Nov.)	20cm	49.17	6.27	4.73	60.10	7.46
	30cm	47.50	6.83	5.07	64.33	7.99
2WBT	10cm	57.00	5.30	4.17	52.83	6.56
(15th Nov.)	20cm	54.00	5.90	4.30	54.57	6.78
	30cm	49.83	6.13	4.53	57.97	7.20
AST	10cm	63.33	5.07	3.93	49.47	6.14
(1st Oct.)	20cm	59.17	5.47	4.13	52.47	6.52
	30cm	55.33	5.97	4.30	56.03	6.96
LSD at 5%		N.S	N.S	0.25	5.44	0.56

N.S:: Not significant

Table 6: Response of quinoa traits to planting dates in 2021/2022 and 2022/2023 seasons

Planting date (A)	Plant height (cm)	No. of panicles /plant	Grain weight/plant (g)	1000-grain weight (g)	Grain yield/fed (kg)	Protein %	Saponin %
			2021/2022 season				
4WBT (1st Nov.)	87.34	17.31	12.52	2.86	518.72	12.78	0.261
2WBT (15th Nov.)	99.14	19.81	13.85	2.86	590.01	12.34	0.247
AST (1st Oct.)	103.00	16.07	11.76	2.89	475.45	12.09	0.224
LSD at 5%	2.53	1.56	0.65	N.S	34.09	0.13	0.013
			2022/2023 season				
4WBT (1st Nov.)	79.40	16.57	11.84	2.84	477.74	12.52	0.251
2WBT (15th Nov.)	96.73	18.46	12.86	2.84	537.02	12.27	0.238
AST (1st Oct.)	100.14	14.14	10.37	2.86	459.00	11.88	0.214
LSD at 5%	2.56	2.36	0.73	N.S	13.10	0.10	0.011

4WBT and 2WBT: planting quinoa 4 and 2 weeks before transplant onion, AST: planting quinoa at the time of transplant onion, N.S: Not significant

This may be due to the germination process is slowed down by low temperatures in December, as shown in Table (2), which in turn reduces the yield. Similar results were obtained by Hirich *et al.* (2014) who explained that lower production with late planting dates was explained by delayed germination as result of low temperatures. In the same respect, Nagib *et al.* (2020) recommended cultivating the quinoa on 15 November compared with first November and December under the conditions of Central Egypt because it gave the best values for yield and its components. Another interpretation, delaying transplant onion gives a good chance for quinoa plants to develop and increase yield and its components. These results are supported by the work done by Sheha *et al.* (2022) who found that as the sowing date of onion became more distant from that of the faba bean, the yield of the faba bean increased. Quality traits of quinoa behaved opposite trend as grain yield as shown in Table (6). Where the highest grain protein content and saponin % were obtained by 4WBT planting date (early sowing date). Proper planting date may enhance biosynthesis processes, photosynthesis and increased carbohydrate % to obtain maximize the yield, which probably decreases the grain protein content of quinoa. These results are supported by findings of Awadalla and Morsy (2017) who reached that the highest value of protein content was recorded with sown quinoa Regalona genotype on 1st November. Hammad *et al.* (2021) exhibited that the saponin and protein percentage in quinoa seeds decreased significantly by a delay in the sowing date.

Quinoa traits response to plant spacing: Results illustrated in Table (7) confirm that plant spacing of quinoa significantly affected all studied traits of quinoa in both grown seasons, except 1000-grain weight was insignificant in both seasons. Planting quinoa at the narrow spacing (10 cm) produced the highest values of plant height. Reducing quinoa plant spacing increased plant height owing to increased intra-specific competition between quinoa plants for basic growth sources, especially solar radiation. This result in line with Erdoğan and Koca (2020) who found that intercropping quinoa with corn at different plant density (plant spacing) had a negative effect on quinoa plant height.

Table 7: Response of quinoa traits to plant spacing in 2021/2022 and 2022/2023 seasons.

Plant spacing (B)	Plant height (cm)	No. of panicles /plant	Grain weight/plant (g)	1000-grain weight (g)	Grain yield/fed (kg)	Protein %	Saponin %
			2021/2022 season				
10 cm	105.36	9.50	9.03	2.83	682.11	12.23	0.257
20 cm	95.00	18.70	12.27	2.88	471.42	12.42	0.244
30 cm	89.13	24.99	16.83	2.90	430.65	12.56	0.231
LSD at 5%	4.38	1.93	0.83	N.S	17.95	0.21	0.011
			2022/2023 season				
10 cm	98.73	8.49	7.95	2.81	627.32	12.07	0.247
20 cm	92.50	17.70	11.60	2.85	452.53	12.21	0.233
30 cm	85.04	22.98	15.51	2.88	393.91	12.39	0.233
LSD at 5%	1.96	1.92	0.63	N.S	13.07	0.1	0.014

N.S:: Not significant

On contrary, the wider plant spacing at 30 cm produced the highest number of panicles/plants, and grain weight/plant (g). The highest increase in these traits of quinoa has been attributed to the avoidance of shading and competition, where there were decreasing competitiveness with the wider spacing. While 10cm as narrow spacing increased intra and inter-specific competition between the two crops and the same crop, respectively, for basic growth resources. Similar results are obtained by Vahidi *et al.* (2021) who reported that in mixed cultivation, millet and quinoa showed substantial effects on each other when intercropped at varying planting densities due to differences in architectural and physiological properties. However, grain yield/fed decreased by 30.9 and 36.9% in 2021/2022 season and by 27.9 and 37.2 % in 2022/23 season with increase of plant spacing from 10 cm to 20 and 30 cm, respectively. This result indicated that the increase in the number of panicles/plants, weight of grains/plant and 1000-grain weight do not compensate for the reduction in quinoa plant density per the unit area. Where the number of quinoa plants per unit area is one of the major factors that determining yield per feddan. In this regard, Cha *et al*., (2016) mentioned that planting density is one of the most important agricultural practices influencing crop yields. These findings are in the same line as those reported by each of Bhargava *et al*. (2007) and Vahidi *et al.* (2021). The highest grain weight per plant (19 g plant^{-1}) was obtained in the intercropping treatment of 20 plants/m^2 of quinoa, while the highest grain yield (4863 kg ha^{-1}) produces with intercropping 30 plants/m^{2}of quinoa with potato (Jalali *et al*., 2021). The highest yield of quinoa seed was obtained by planted quinoa at 20 cm plant spacing, while the lowest yield of quinoa was obtained from the plant spacing 10 cm (Araghian *et al*., 2021). This fluctuation between the two studies may be due to the companion crop. With respect to grain quality, increasing plant density of quinoa, by reducing plant spacing to 10 cm, led to decrease grain protein content while reverse occurred for saponin %. The highest protein content (12.56 and 12.39%) produces by 30 cm plant spacing, while 10 cm had the highest saponin % (0.257 and 0.247%) in first and second season, respectively. Similar results were obtained by Eisa et al. (2017) the higher plant density that gives higher seed yield is associated with significant reduction in seed quality in terms of protein content. In the same connect, Hammad *et al*. (2021) gradual increases in the concentrations of saponin and carbohydrates was associated with increasing plant density, while the protein% behaved the opposite trend.

Quinoa traits response to interaction effect: The number of panicles/plants, grain weight/plant and grain yield/fed were significantly affected by the interaction between the quinoa planting date and spacing in the two growing seasons, as shown in Table (8). The highest values of the number of panicles/plants, and grain weight/plant produced with planted quinoa at 2WBT of onion and 30 cm plant spacing. Quinoa planting in mid-November to early December secured good plant development particularly at wider spacing, compared to late sowing date at narrow spacing (Hirich *et al*., 2014). These results are in harmony to those obtained by Nagib *et al.* (2020) the highest values of number of panicles/plant and seed yield per plant were obtained from planting date on November 15th with the widest plant space (20 cm) in both seasons. The trend of grain yield with interaction behaved similarly to grain yield as affected by individual factor. It is clear from Table (8) that the highest grain yield/fed (747.87 and 687.13kg/fed) was obtained by narrow plant spacing at 10 cm with planting date 2WBT of onion in first and second season, respectively. These results are in the same line with the results were detected Bhargava et al. (2007). The maximum seed yield/fed achieved with planting quinoa on November 15th in combination with 10 cm planting space in both seasons (Nagib et al., 2020).

Correlation coefficient:-

1- Onion crop: Table (9) presents the correlation coefficient between onion yield and other important onion traits at different quinoa sowing dates (4, 2 WBT and AST) and plant spacing (10, 20, and 30cm) in both growing seasons. This type of analysis can be used as a suitable tool to regulate any positive trait closely related to the onion yield obtained. The correlation coefficient indicated a strong positive correlation between onion yield and studied traits (No. of leaves /plants, bulb diameter, bulb weight) at planting dates and spaces for onion in both two growing seasons. Similar results were obtained by (Semida *et al*., 2021).

2- Quinoa crop: In addition, simple correlation coefficients between quinoa yield at previous sowing systems and other quinoa traits in both growing seasons were estimated (Table, 10). Results indicated that plant height was positively and significantly associated with quinoa yield at planting dates 30 days, 15 days and at the same time in both growing seasons. Otherwise, 1000-grain weight was negative and significantly associated with quinoa yield at the same previous sowing systems in both growing seasons. Moreover, No. of panicles and grain weight/plant were positively and significantly associated with quinoa yield at all studied planting spaces in both seasons. The current results were confirmed by the results detected by Awadalla and Morsy (2017), who found that strong correlation between the yield and its components in both seasons.

Competitive Indexes: Land equivalent ration (LER) Results in Table (11) clearly show that the averaged values of LER were greater than 1.0, which indicates the usefulness of intercropping compared to pure culture. These results also indicated that relative yield of quinoa planting at spacing 10 cm (75% of its sole plant density) was ever higher than those of the relative yield of onion. Therefore, it confirms that quinoa crop more competitor than onion crop. Also, values of LER increased with increasing quinoa plant density by sown it at a spacing of 10 cm. These results are in agreement with Araghian et al. (2021) who showed that, increasing the share of quinoa in the quinoa/ guar intercropping system, led to an increase in total LER. Also, in this direction, the highest LER values were produced by intercropping quinoa at 10 cm spacing with both of the planting dates 4WBT and/or 2WBT, which was 1.46 and 1.42 in first and second season, respectively. Meanwhile, the lowest LER values 1.13 and 1.16 were achieved by intercropping quinoa at 30 cm and simultaneously with onion in 2021/2022 and 2022/2023, respectively. In the same trend, the planting date and density (spacing) had a significant effect on the LER of intercrops, quinoa and guar as reported by Araghian *et al*., (2021), and also with quinoa and millet as detected by Vahidi *et al*., (2021), and with quinoa and potato as proposed by Jalali *et al*., (2021) and as well as with faba bean and onion as reported by Sheha *et al*., (2022).

Table 8: Response of quinoa traits to interaction effect of planting dates and spacing of quinoa in 2021/2022 and 2022/2023 seasons.

Planting date (A)	Plant spacing	Plant height (cm)	No. of panicles /plant	Grain wt. /plant (g)	1000-grain wt. (g)	Grain yield/fed (kg)	Protein %	Saponin %
				2021/2022 season				
4WBT	10cm	96.17	9.43	8.98	2.82	675.86	12.63	0.273
(1st Nov.)	20cm	87.73	18.53	12.37	2.87	467.43	12.80	0.260
	30cm	78.13	23.97	16.37	2.89	412.86	12.90	0.250
2WBT	10cm	107.67	10.57	9.73	2.83	747.87	12.27	0.263
(15th	20cm	96.53	20.63	13.27	2.86	527.96	12.30	0.247
Nov.)	30cm	93.23	28.23	18.55	2.89	494.20	12.47	0.230
AST	10cm	112.23	8.50	8.38	2.86	622.60	11.80	0.233
(1st Oct.)	20cm	100.73	16.93	11.17	2.90	418.86	12.17	0.227
	30cm	96.03	22.77	15.73	2.93	384.90	12.30	0.213
LSD at 5%		N.S	2.73	1.45	N.S	31.09	N.S	N.S
				2022/2023 season				
4WBT	10cm	87.13	8.47	7.90	2.81	607.13	12.40	0.267
(1st Nov.)	20cm	79.53	18.03	12.01	2.84	446.83	12.53	0.247
	30cm	71.53	23.00	15.45	2.87	379.26	12.63	0.240
2WBT	10cm	102.77	9.37	8.63	2.81	687.13	12.10	0.250
(15th	20cm	96.53	19.83	12.75	2.84	492.26	12.26	0.240
Nov.)	30cm	90.90	26.17	17.20	2.87	431.66	12.43	0.223
AST	10cm	106.30	7.43	7.33	2.82	587.70	11.70	0.223
(1st Oct.)	20cm	101.43	15.23	10.05	2.86	418.50	11.83	0.213
	30cm	92.70	19.77	13.72	2.89	370.80	12.10	0.207
LSD at 5%		N.S	1.96	1.99	N.S	22.64	N.S	N.S

4WBT and 2WBT: planting quinoa 4 and 2 weeks before transplant onion, AST: planting quinoa at the time of transplant onion, N.S: Not significant

Table (9): Correlation coefficient of onion traits at quinoa planting dates and spacing.

	10cm	20cm	30cm	30 days	15 days	at the same time
			2021/2022 season			
plant height	-0.88067**	-0.85013**	-0.73502*	-0.67822*	-0.89664**	-0.89017**
No. leaves/plant	0.724378*	0.645544	0.61821	0.390025	0.601519	0.229941
bulb diameter	0.963986**	0.886873**	0.830491**	0.9465**	0.97854**	0.924588**
bulb weight	0.628276	0.783301*	0.884854**	0.903363**	0.724418*	0.742788*
			2021/2022 season			
plant height	-0.77091*	-0.87418**	-0.72918*	-0.4959	-0.89673**	-0.79098*
No. leaves/plant	0.537031	0.655088	0.867062**	0.797087*	0.697894*	0.815668**
bulb diameter	0.769943*	0.864822**	0.790554*	0.858695**	0.668475*	0.618556
bulb weight	0.871827**	0.862951**	0.92154**	0.418989	0.889276**	0.812663**

*,**: significant level at 5% and 1% of probability.

Table (10): Correlation coefficient of quinoa traits at quinoa planting dates and spacing.

	10cm	20cm	30cm	30days	15days	at the same time
			2021/2022 season			
Plant height	-0.13259	-0.14375	0.07921	0.903234**	0.943784**	0.962784653**
No. of panicles	0.809597**	0.905499**	0.888497**	-0.97796**	-0.93416**	-0.941975693**
Grain wt./plant	0.671553*	0.915292**	0.992805**	-0.91198**	-0.84576**	-0.841539874**
1000- grain wt.	-0.54651	-0.64618	-0.41286	-0.92612**	-0.80004**	-0.902022354**
			2022/2023 season			
Plant height	0.148618	-0.14379	0.272148	0.925916**	0.942566**	0.84224188**
No. of panicles	0.774204*	0.868384**	0.851214**	-0.99471**	-0.97986**	-0.969994616**
Grain wt./plant	0.920001**	0.850689**	0.742139*	-0.97757**	-0.9412**	-0.894093146**
1000- grain wt.	-0.05582	-0.49823	-0.54337	-0.92447**	-0.79154*	-0.880356671**

*,**: significant level at 5% and 1% of probability.

Table 11: Response of land equivalent ratio and aggressivity to interaction effect of planting dates and spacing of quinoa in 2021/2022 and 2022/2023 seasons.

Planting date (A)	spacing	L_{onion}	L_{quinoa}	LER	A_{onion}	A_{quinoa}	L_{onion}	L_{quinoa}	LER	A_{onion}	A_{quinoa}
		2021/2022 season					2022/2023 season				
4WBT (1st Nov.)	10cm	0.66	0.80	1.46	-0.26	0.26	0.67	0.75	1.42	-0.17	0.17
	20cm	0.69	0.55	1.24	-0.61	0.61	0.73	0.56	1.29	-0.58	0.58
	30cm	0.76	0.49	1.25	-0.93	0.93	0.78	0.47	1.25	-0.85	0.85
2WBT (15th Nov.)	10cm	0.63	0.83	1.46	-0.40	0.40	0.64	0.78	1.42	-0.28	0.28
	20cm	0.66	0.59	1.25	-0.77	0.77	0.66	0.56	1.22	-0.69	0.69
	30cm	0.70	0.55	1.25	-1.26	1.26	0.70	0.49	1.19	-1.03	1.03
AST (1st Oct.)	10cm	0.61	0.74	1.35	-0.26	0.26	0.60	0.74	1.34	-0.29	0.29
	20cm	0.64	0.50	1.14	-0.54	0.54	0.64	0.53	1.17	-0.63	0.63
	30cm	0.67	0.46	1.13	-0.94	0.94	0.68	0.47	1.15	-0.97	0.97

4WBT and 2WBT: planting quinoa 4 and 2 weeks before transplant onion, AST: planting quinoa at the time of transplant onion,

Results in Table (11) clearly show that the averaged values of LER were greater than 1.0, which indicates the usefulness of intercropping compared to pure culture. These results also indicated that relative yield of quinoa planting at spacing 10 cm (75% of its sole plant density) was ever higher than those of the relative yield of onion. Therefore, it confirms that quinoa crop more competitor than onion crop. Also, values of LER increased with increasing quinoa plant density by sown it at a spacing of 10 cm. These results are in agreement with Araghian *et al.* (2021) who showed that, increasing the share of quinoa in the quinoa/ guar intercropping system, led to an increase in total LER. Also, in this direction, the highest LER values were produced by intercropping quinoa at 10 cm spacing with both planting dates 4WBT and/or 2WBT, which was 1.46 and 1.42 in first and second season, respectively. Meanwhile, the lowest LER values 1.13 and 1.16 were achieved by intercropping quinoa at 30 cm and simultaneously with onion in 2021/2022 and 2022/2023, respectively. In the same trend, the planting date and density (spacing) had a significant effect on the LER of intercrops, quinoa and guar as reported by Araghian *et al*., (2021), and also with quinoa and millet as detected by Vahidi *et al*., (2021), and with quinoa and potato as proposed by Jalali *et al*., (2021) and as well as with faba bean and onion as reported by Sheha *et al*., (2022).

Aggressivity: It is clear from the results in Table (11), aggressivity values of both crops are constant, with different planting date and spacing of quinoa. Where the aggressivity values of onion were negative, whereas those of quinoa were positive. This indicates that quinoa plants have more competitive ability. This result may be due to quinoa overstory component while onion understory component. This is agreement with the results detected by Sheha *et al.* (2022) who are found that the aggressivity values were negative for intercropped onion and positive for faba bean crop.

Gross and net income: There is a discrepancy between the two growing seasons in gross and net income, as shown in Table (12). Intercropping quinoa with onion gave increasing in gross income and net income as compared to sole planting of onion, in 2021/2022 season. Meanwhile, sole planting of onion superior all intercropping systems, except treatment of intercropping quinoa 2 and 4 weeks before transplant onion at 10 cm, in 2022/2023 season. This variations between the two growing seasons may be due to the high fluctuation in onion price (one and half pound per kg in the first season versus ten pounds per kg in the second one). The increase in onion prices in the second season may be due to the rains falling in April month during the harvest season, which led to damage and losses in the crop and less supply in the market compared to the first season. However, the highest gross income and net income were obtained by intercropping quinoa 2 weeks before transplant onion at plant spacing 10 cm between hills in the two growing seasons. This confirm that appropriate planting date and spacing of intercropping increased income stability and reduce the risk of market glut and falling prices. The intercropping quinoa helps to enrich biodiversity, better utilization of environmental resources, and improve farm income (Devkota Wasti and Nangia, 2021).

Table 12: Response of gross and net income to interaction effect of planting dates and spacing of quinoa in 2021/2022 and 2022/2023 seasons.

Interaction (A x B)		Yield of sole crop (fed)	Income of (L.E/fed)		Gross income L.E/fed	Total cost L.E/fed	Net income L.E/fed
			onion	Quinoa			
2021/2022 season							
4WBT	10cm	850.0 kg	12342	18721	31063	18360	12703
(1st Nov.)	20cm		12892	12948	25839	18360	7479
	30cm		14122	11436	25558	18360	7198
2WBT	10cm	902.4 kg	11736	20716	32452	18360	14092
(15th Nov.)	20cm		12264	14624	26888	18360	8528
	30cm		13008	13689	26697	18360	8337
AST	10cm	842.7 kg	11332	17246	28578	18360	10218
(1st Oct.)	20cm		11820	11602	23422	18360	5062
	30cm		12439	10662	23101	18360	4741
Sole onion		12.40 ton	18603	-	18603	16450	2153
2022/2023 season							
4WBT	10cm	804.5 kg	68800	38249	107049	22950	84099
(1st Nov.)	20cm		74640	28150	102790	22950	79840
	30cm		79897	23893	103790	22950	80840
2WBT	10cm	878.8 kg	65617	43289	108906	22950	85956
(15th Nov.)	20cm		67767	31012	98779	22950	75829
	30cm		71990	27195	99185	22950	76235
AST	10cm	791.2 kg	61433	37025	98458	22950	75508
(1st Oct.)	20cm		65157	26366	91522	22950	68572
	30cm		69590	23360	92950	22950	70000
Sole onion		10.26 ton	102600	-	102600	20563	82038

4WBT and 2WBT: planting quinoa 4 and 2 weeks before transplant onion, AST: planting quinoa at the time of transplant onion

CONCLUSION

Quinoa is a crop that can withstand harsh environmental conditions and adapt to climate change. However, there is no opportunity for its inclusion in the crop structure because of competition between the main crops on the cultivated area. To overcome this issue. The current study suggests intercropping quinoa with onions to introduce quinoa into the Egyptian cropping structure and expand its cultivation in sandy and marginal areas. Intercropping quinoa 2 weeks before transplanting onion at plant spacing 10 cm apart produced 6.67 ton/fed of onion, in addition to produced 717.5 kg/fed seed of quinoa. Which increased the net income by 17 % and land use by 44%, as averaged of both seasons, as well as reduce risk of climatic change on sole planting of onion.

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إمكانية إدخال الكينوا بالتركيب المحصولي المصرى بالتحميل مع البصل

هدفت الدراسة الحالية إمكانية إدخال الكينوا في التركيب المحصولى بالأراضي الرملية من خلال التحميل مع البصل وللتخفيف من تأثير تغير المناخ. ولتحقيق هذا الهدف أجريت هذه الدراســـة الحقلية خلال موســـمي 2022/2021 و 2023/2022 بالمزرعة البحثية بمحطة البحوث الزراعية بالإسماعيلية ، مركز البحوث الزراعية ، مصر، حيث تم دراسة تأثير ثلاثة مواعيد زراعية لزراعة نبات الكينوا محملة مع البصل وهى: (4أسابيع قبل شتل البصل، أسبوعين قبل شتل البصل ، و في نفس ميعاد شتل البصل) و كذلك تأثير ثلاثة مسافات لزراعة نباتات الكينوا وهى: (10 و 20 و 30 سم) على إنتاجية كلا المحصولين وصفات الجودة في الكينوا ودخل المزارع. أشارت النتائج إلى أن زراعة الكينوا قبل شتل البصل بأسبوعين وعلى مسافة 10 سم حققت أعلى محصول من حبوب الكينوا للفدان، في حين أن زراعة الكينوا قبل شتل البصل ب 4 أسابيع قد سجل أعلى القيم لصفات جودة الكينوا عن طريق زراعة الكينوا على مسافة زراعة 30 سم لمحتوى الحبوب من البروتين وعلى مسافة زراعة 10 سم ل % للسابونين. كذلك تحقق أعلى محصول من البصل من زراعة الكينوا قبل شتل البصل ب4 أسابيع وعلى مسافة زراعة 30 سم. أيضا سجلت النتائج أن أعلى قيم للمكافئ الأرضى LER (1.46 و 1.42) وكذلك إجمالي وصافي الدخل كانت عند زراعة الكينوا قبل شتل البصل بأسبوعين وعلى مسافة زراعة 10 سم في الموسم الأول والثاني على التوالي. على الرغم من تقلبات أسعار البصل في كلا الموسمين بسبب تغير المناخ (هطول الأمطار)، وتأثيرها على الإنتاج، فإن تحميل الكينوا مع البصل حقق عائدًا نقدى أعلى وأكثر استقرارًا من زراعة البصل بمفرده في أي من الموسمين. وبناءاً عليه، يمكن إدخال الكينوا بالتركيب المحصولى ومن ثم التوسع فى زراعتها بالأراضي الرمليه والهامشيه بزراعة الكينوا قبل أسبوعين من شتل البصل وعلى مسافة زراعة 10 سم لزيادة كفاءة إستخدام الأرض وصافي الدخل للمزارع قياساً بالزراعة المنفردة للبصل.

الكلمات المفتاحية: الكينوا، البصل، التحميل، مواعيد الزراعة، مسافة الزراعة، صفات الجودة، المحصول، المكافئ الأرضي، دخل المزارع