RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
54 (5) 1171-1182, 2022
http://doi.org/10.54910/sabrao2022.54.5.18
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

RESPONSE OF HIGH-YIELDING PEANUT CULTIVARS TO VARIOUS SEED TREATMENTS UNDER MARGINAL FERTILITY SANDY SOIL CONDITIONS

A.A.A. ELNAGAR[*], E.M. ZEIDAN, A.A. ABDUL-GALIL, and A.A-G. ALI

Department of Crop Science, Faculty of Agriculture, Zagazig University, Zagazig, Egypt
[*]Corresponding author's emails: alaaelngar@agri.zu.edu.eg, alaaelngar954@gmail.com
Email addresses of co-authors: elsayedzeidan954@gmail.com, ahmedabdulgalil632@gmail.com, ahmedabdulgani975@gmail.com

SUMMARY

Ameliorating peanut production is a requirement to cope with the abrupt climate change and burgeoning population. Seed treatment is vital for enhancing and sustaining peanut production, particularly in semiarid environments. The latest study aimed to evaluate the impact of different seed treatments on the agronomic and quality of three high-yielding peanut cultivars: Giza-6, North Carolina (N.C.), and Aramanch. The applied seed treatments include *Rhizobium* inoculation, moringa leaf extract, vitavax, and gypsum versus untreated control. The evaluated peanut cultivars significantly varied in their results for agronomic and quality traits. The cultivar Giza-6, followed by Aramanch, proved the best displaying the highest number of seeds per pod, number of pods per plant, 100-seed weight, number of branches per plant, shelling percentage, biological yield, pod yield, seed yield, oil yield, and protein yield. The applied seed treatments substantially enhanced peanut yield traits, oil, and protein content of peanuts with the superiority of *Rhizobium* inoculation, gypsum, and moringa extract. These treatments effectively reinforced peanut growth, positively reflected in the yield and quality traits. Subsequently, integrating the seed treatments, particularly *Rhizobium* inoculation, gypsum, and moringa extract, with high-yielding cultivars, such as Giza-6 and Aramanch, confirmed a helpful approach to enhancing and sustaining peanut production in arid environments.

Keywords: yield traits, oil content, crude protein**,** interaction effect, heatmap, and hierarchical clustering

Key findings: The assessed peanut cultivars exhibited significant differences in all agronomic and quality traits, with Giza-6 and Aramanch proving superior. The applied seed treatments enriched peanut yield traits, oil, and protein content of peanuts, with the superiority of *Rhizobium* inoculation, gypsum, and moringa extract.

Communicating Editor: Prof. Dr. Sanun Jogloy

Manuscript received: September 6, 2022; Accepted: November 1, 2022.

INTRODUCTION

Peanut (*Arachis hypogaea* L.) is a major legume crop cultivated predominantly for its edible seeds. It is extensively grown in the tropics, beneficial to large and small commercial producers (Ali *et al*., 2022; Popoola *et al*., 2022). Classified as a grain legume, it gives high oil content as an oil crop. Global annual production of shelled peanuts reached 53.6 million t, from 31.5 million ha in 2020 (FAOSTAT, 2022). Peanut functions as an

To cite this manuscript: Elnagar AAA, Zeidan EM, Abdul-Galil AA, Ali AA-G (2022). Response of high-yielding peanut cultivars to various seed treatments under marginal fertility sandy soil conditions. *SABRAO J. Breed. Genet.* 54(5): 1171-1182. http://doi.org/10.54910/sabrao2022.54.5.18.

annual summer crop in Egypt, with a total cultivated area of 64,000 ha, a total production of 213,800 t, and an average of 3.34 t/ha, in the 2020 season. Peanut attests as one of the most basic cash and food crops (Carvalho *et al*., 2018; Li *et al.*, 2018). It is a crop of economic worth, having a valuable source of several nutrients. Peanut it contains 25% protein and 50% edible oil, thus, considered highly nutritious (Javanmardi *et al.*, 2022). It serves numerous uses, i.e., in the form of edible oil, shelled nuts, or distinct processing forms, such as, peanut butter, flour, sauce, or confectionery items (Koolachart *et al*., 2019; Yin *et al.*, 2022). Accordingly, deciding to improve its production to ensure global food security with the current population growth and the threat of environmental pressures proves valid.

Genotypes exhibited contrasting performances under different agricultural practices (Gracia *et al.*, 2012; Ponce-Molina *et al.*, 2012; Gharib *et al.*, 2021; Desoky *et al.*, 2021; Habibullah *et al.*, 2021; Mansour *et al.*, 2021a; Swailam *et al.*, 2021; Omar *et al.*, 2022). Peanut cultivars differ in chemical composition, germination, vigor, fungi infection, and storability (Bera *et al.*, 2019). Consequently, assessing peanut genotypes to explore those with enhanced efficiency in employing agricultural practices is essential for its future sustainable production (Cantonwine *et al.*, 2011; Kamara *et al.*, 2022; Sakran *et al.*, 2022). Peanut genotypes display substantial differences in their responses to seed treatments (Khetrin *et al.*, 2018; Nayak *et al.*, 2020; Aderiye *et al.*, 2021).

Seed treatments are an efficacious and feasible approach to enhancing plant growth and productivity (El-Sanatawy *et al.*, 2021a). Symbiotic nitrogen fixation by legumes has a decisive role in preserving soil fertility and sustaining crop productivity in arid environments (Mansour *et al.*, 2021b). Peanut, like other legumes, forms a symbiosis relationship with rhizobia (Bogino *et al.*, 2006). The most associated role is to promote legume-*Rhizobium* symbiosis in photo-hormones, induce root growth stimulation, and provide more sites for rhizobia nodulation (Mahrous *et al.*, 2015; El-Hady *et al.*, 2022). Gypsum is one of the most primitive fertilizer forms utilized in peanut production. Gypsum provides a soluble source of vital plant nutrients, such as, calcium and sulfur, and can enhance overall plant growth (Prakash *et al.*, 2020). It promotes seedling emergence and boosts water infiltration rates and movement through the soil profile. It can also diminish losses of nutrients and concentrations of soluble phosphorus in surface water runoff (Rashmi *et al.*, 2018).

Diseases cause considerable losses in peanut production (Naab *et al.*, 2005). Fungal and bacterial pathogens damage the crop at different stages of growth and cause acute yield losses, and in some cases, destroy seed quality (Nazarov *et al.*, 2020; Kamara *et al.*, 2021a). Though certain plant infections are manageable through resistant genotypes and modification of agricultural practices, various diseases are only managed adequately with an appropriate fungicide (Jadon *et al.*, 2015). A suitable means of applying crop protection treatments include treating the seed. Seed treatments proved remarkably effective since they can protect young plants during a sensitive stage in their development (Ashraf and Foolad, 2005; El-Sanatawy *et al.*, 2021b; Selem *et al.*, 2022). Fungicide seed treatment as inexpensive protection for peanut helps seed growers and producers. Appropriate fungicide application supports better performance of plant growth, increasing the seed yield and quality (Rocha *et al.*, 2019). Moreover, *Moringa oleifera* extracts had different degrees of antifungal activity against tested pathogens (El-Mohamedy and Abdalla, 2014). Moringa extract decreases the opportunity for fungal disease, provides seed vigor, and enhances plant growth (Nwangburuka *et al.*, 2012). Previous reports exist on several studies related to seed treatment and its contribution to enhancing peanut production. However, no existing studies focus on the comparison of different seed treatments, such as, *Rhizobium* inoculation, moringa leaf extract, vitavax, and gypsum, on the agronomic and quality of diverse high-yielding peanut cultivars. Based on the results of previous investigations, this study hypothesized that the applied seed treatments would notably improve peanut growth, positively reflected in yield and quality traits. Accordingly, the recent investigation was to study the diverse performance of three peanut cultivars under different seed treatments (*Rhizobium* inoculation, moringa leaf extract, vitavax, and gypsum) to define the proper cultivar which achieves high pod, seed, oil, and protein yields**.**

Table 1. Monthly average minimum (Min) and maximum (Max) temperatures, relative humidity (RH), and total rainfall (Rain) in the 2019 and 2020 growing seasons, as well as, 25-year monthly averages (1995–2020).

Month	Min (° C)	Max (° C)	RH (%)	Rain (mm)
	Season 2019			
May	15.58	32.73	58.87	0
June	19.03	37.05	47.76	0
July	22.11	40.29	45.52	0
August	22.63	40.25	47.71	0
September	22.44	38.95	54.73	0
	Season 2020			
May	18.43	36.16	39.79	0
June	19.88	37.87	44.26	0
July	22.89	40.49	43.91	0
August	23.61	40.73	46.22	0
September	21.72	37.03	52.93	0
	25-year average (1995-2020)			
May	16.98	33.54	42.05	0.33
June	19.70	37.94	39.91	0.11
July	22.21	39.17	41.66	0.11
August	22.82	38.92	45.11	0.11
September	20.87	36.18	49.68	0.05

MATERIALS AND METHODS

Experimental site and experimental design

Two field experiments proceeded at the Experimental Farm of the Faculty of Agriculture, Khattara, Egypt ((30°36′ N, 31°46′ E) during two summer seasons of 2019 and 2020. The experimental site was dry, with no precipitation in the two summer seasons (Table 1). The soil comprised sandy (*i.e.*, 93.34% sand, 2.54% silt, and 4.12% clay). The organic matter and pH were 0.85% and 8.14, respectively. The available nutrients included 19.7 mg N, 10.4 mg P, and 81 mg K per kg soil. A split plot design of three replications took place. The evaluated cultivars received allocations in the main plots, while seed treatments took place in subplots. The sub-plot area measured 9 m^2 (3m×3m), having four rows 75 cm apart in width and 3 m long. Sowing took place on 12 and 19 May in the first and second seasons, respectively. Calcium superphosphate (15.5% P_2O_5) at a rate of 450 kg/ha and potassium sulfate (48% k_2O) at 240 kg/ha directly took place after sowing. Nitrogen fertilizer, in the form of ammonium sulfate (20.5% N) at a rate of 35 kg/ha, proceeded application at sowing as a starter N dose for boosting plant growth and ensuring uniform plant stands. The other recommended cultural practices for peanut cultivation, drip irrigation, and weed and insect control ensued.

Plant material and seed treatments

The evaluated peanut cultivars were Giza-6, North Carolina (N.C.), and Aramanch, obtained from the Agricultural Research Center, Egypt. The peanut seeds underwent separate treatment with *Rhizobium* inoculation, moringa leaf extract, vitavax (Carboxin 37.5% + Thiram 37.5%), and gypsum versus untreated control. Inoculation application used an Okadeen bag, with the peanut seeds mixed well with sugar solution and spread on a plastic sheet under shading. The treated seed by vitavax received separate inoculation and was added alone in a row after sowing. Five hundred grams of moringa leaves were air dried in the open air for 10 days, then dried in an air oven at 45^{o}C for two days until gaining constant weight. Dried leaves were ground, sieved, and maintained away from light and moisture until utilized in the extract preparation. The 500 g of the leaves powder were soaked in 1500 ml of the solvent (Ethanol) for four days and filtered through Whatman No.1 filter pepper over Anhydride Sodium Sulphate. The extract proceeded to evaporation by a rotary evaporator (temperature up to 50°C). After extraction, preparing the stock solution occurred, with a prepared dilute solution containing a concentration of 2%. Peanut seeds emerged in moringa ethanol extract, then sprayed in filter paper for drying, and seed moisture content reached 10±2%. The peanut seeds gained treatment with the recommended dose (2g/kg) of the fungicide vitavax. The gypsum treatment application began at the flowering stage (around 30 days from sowing) at the rate of 1200 kg/ha.

Measured traits

Yield traits

At harvest, random picking of a sample of 10 plants occurred from the second ridge to measure the number of branches per plant, number of pods per plant, pods weight per plant, seed weight per plant, number of seeds/pod, seed index (100-seed weight), and shelling percentage. The final pod yield (kg/ha) ensued by harvesting all plants in the third and fourth ridges. The shelling percentage was calculated by dividing seed yield by pod yield as parentage.

Seed oil and protein contents (%)

A sufficient amount of dried peanut seeds underwent milling to a fine powder. Then, processing constant samples of dried fine powder helped determine peanut seeds' oil and total nitrogen contents. Seed oil content determination used the Soxhlet apparatus and extracted by petroleum ether (60°C–80°C) for 12 h. The total determined nitrogen used the modified micro Kjeldahl method. Total nitrogen was multiplied by 6.25 to obtain crude protein content. Afterward, oil and crude protein yields/ha calculations by multiplying their contents by seed yield/ha.

Statistical analysis

The data underwent the analysis of variance of split-plot design employing R statistical software version 4.1.1 (R Core Team, 2022) while separating the differences among evaluated cultivars and seed treatments using Tukey's HSD test ($P \leq 0.05$). The heatmap and hierarchical clustering (Kolde, 2019) explored the associations among evaluated traits.

RESULTS AND DISCUSSION

Yield attributes

The seed treatments and the interaction between cultivars and seed treatments influenced plant height significantly, as presented in Table 2 and illustrated graphically in Figure 1. However, nonsignificant differences showed between the evaluated cultivars for plant height. The seed treatments of gypsum, moringa extract, and vitavax exhibited longer plants versus the other treatments. Such treatments appeared to stimulate and protect peanut plants (Table 2). The peanut cultivars, seed treatments, and their interaction demonstrated a highly relevant impact on the number of branches per plant, number of pods per plant, number of seeds per pod, and 100-seed weight (Table 2). The cultivars Giza-6 andAramanch produced a higher number of branches per plant, number of pods per plant, number of seeds per pod, and 100-seed weight compared with cultivar N.C., which possessed

Table 2. Influence of different seed treatments on plant height, number of branches per plant, total dry weight per plant, number of pods per plant, and number of seeds per pod of three peanut cultivars*.*

Studied factor	Plant height (cm)	No. of branches/plant	No. of pods/plant	No. of seeds/pod	100-seed weight (g)
Cultivars (C)					
Giza-6	78.88	6.27 ^{a}	50.83 ^{a}	2.03 ^{a}	89.78 ^{a}
N.C.	78.49	5.60 ^{b}	37.39 ^{c}	1.92 ^{c}	87.13 ^{b}
Aramanch	79.03	6.34 ^{a}	45.25 ^{b}	1.98 ^{b}	86.95 ^{b}
Seed Treatments (S)					
Inoculation	77.55 ^{b}	6.27 ^{a}	49.26 ^{a}	1.97 ^{b}	93.13 ^{a}
Gypsum	81.66 ^{a}	6.30 ^{a}	48.35 ^{b}	2.02 ^{a}	92.66 ^{ab}
MLE*	81.41 ^{a}	6.16 ^{ab}	48.23 ^{b}	2.04 ^{a}	91.86 ^{b}
Vitavax	81.14 ^{a}	5.91 ^{bc}	40.35 ^{c}	1.98 ^{b}	83.24 ^{c}
Control	72.24 ^{c}	5.27 ^{c}	35.07 ^{d}	1.86 ^{c}	78.51 ^{d}
ANOVA					
Cultivars (C)	0.124	< 0.001	< 0.001	< 0.001	< 0.001
Seed Treatments (S)	< 0.001	0.013	< 0.001	< 0.001	< 0.001
C×S	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

*MLE: Moringa seed extract

Means followed by different letters under the cultivars or seed treatments are significantly different by Tukey's HSD test at $P \leq 0.05$.

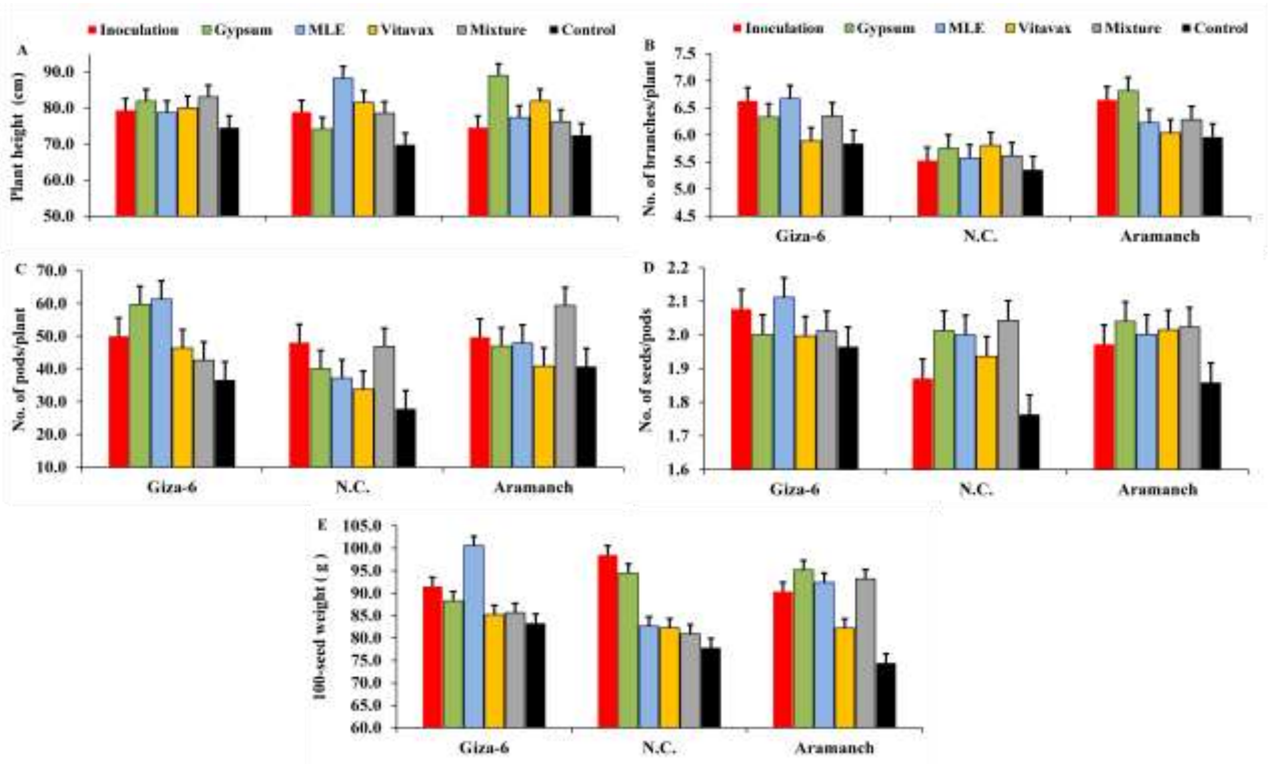

Figure 1. Impact of seed treatments on plant height (A), number of branches per plant (B), number of pods per plant (C), number of seeds per pod (D), and 100-seed weight (E) of three peanut cultivars. The bars on the columns represent the HSD ($P < 0.05$).

the lowest values (Table 2). Concerning the seed treatments, *Rhizobium* inoculation, gypsum, and moringa extract applications exhibited the highest number of branches per plant, number of pods per plant, number of seeds per pod, and seed index (Table 2). Otherwise, the untreated control mostly recorded the lowest values.

The results of the impact interaction between peanut cultivars and seed treatment indicated that the longest plants resulted for Aramanch when treated with gypsum, followed by Giza-6 treated with gypsum (Figure 1). Contrastingly, the lowest value came out for the untreated three cultivars. The Aramanch with *Rhizobium* inoculation and gypsum treatments produced the highest number of branches per plant, followed by Giza-6 treated with *Rhizobium* inoculation, gypsum, and moringa extract. Giza-6 treated with moringa extract, gypsum, and *Rhizobium* inoculation, as well as, Aramanch treated with *Rhizobium* inoculation possessed the highest number of pods per plant. Likewise, Giza-6 treated with *Rhizobium* inoculation and moringa extract and Aramanch treated with gypsum exhibited the highest seed number per pod. Further, Giza-6 with moringa extract and *Rhizobium* inoculation treatments gave the heaviest seed index, followed by N.C. treated with *Rhizobium* inoculation and gypsum and Aramanch with gypsum.

Yield traits

Peanut cultivars, seed treatments, and their interaction displayed highly significant effects on the pod yield per plant, seed yield per plant, biological yield per plant, shelling percentage, pod yield per hectare, and seed yield per hectare (Table 3). Notably, the cultivars Giza-6 and Aramanch achieved a heavier weight of pods/plant, seeds weight per plant, biological yield per plant, shelling percentage, seed yield per hectare, and pod yield per hectare compared with N.C., which recorded the lightest values. The results indicate that peanut cultivars varied in their yield potential mainly due to the genetic impact. These results showed similarity to the patterns of the number of branches per plant, number of pods per plant, number of seeds per pod, and 100-seed weight (Table 3).

Table 3. Influence of different seed treatments on 100- seed weight, the weight of pods per plant, the weight of seed per plant, shelling percentage, pod yield, and seed yield of three peanut cultivars.

Studied factor	Pod yield (g/plant)	Seed yield (g/plant)	Biological yield g/plant	Shelling %	Pod yield (kg/ha)	Seed yield (kg/ha)
Cultivars (C)						
Giza-6	83.55 ^{a}	46.71 ^{a}	315.0 ^{a}	62.13 ^{a}	5372 ^{a}	3322 ^{a}
N.C.	61.97 ^{c}	37.80 ^{c}	240.1 ^{b}	50.70 ^{c}	3796 ^{c}	2028 ^{c}
Aramanch	78.31 ^{b}	40.24 ^{b}	251.3 ^{b}	57.43 ^{b}	4616 ^{b}	2687 ^{b}
Seed Treatments (S)						
Inoculation	72.84 ^{d}	44.41 ^{b}	274.8 ^{c}	60.28 ^{a}	4695 ^{c}	2944 ^{a}
Gypsum	81.82 ^{b}	46.99 ^{a}	282.5 ^{b}	58.84 ^{b}	4944 ^{b}	2858 ^{b}
MLE*	83.09 ^{a}	46.25 ^{a}	293.6 ^{a}	60.71 ^{a}	5107 ^{a}	2826 ^{b}
Vitavax	77.13 ^{c}	38.60 ^{c}	257.7 ^{d}	58.24 ^{b}	4390 ^{d}	2570 ^{c}
Control	55.65 ^{e}	31.68 ^{d}	236.1 ^{e}	45.70 ^{c}	3838 ^{e}	2198 ^{d}
ANOVA						
Cultivars (C)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Seed Treatments (S)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
C×S	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

*MLE: Moringa seed extract
Means followed by different letters under the cultivars or seed treatments are significantly different by Tukey's HSD test at *P* ≤ 0.05.

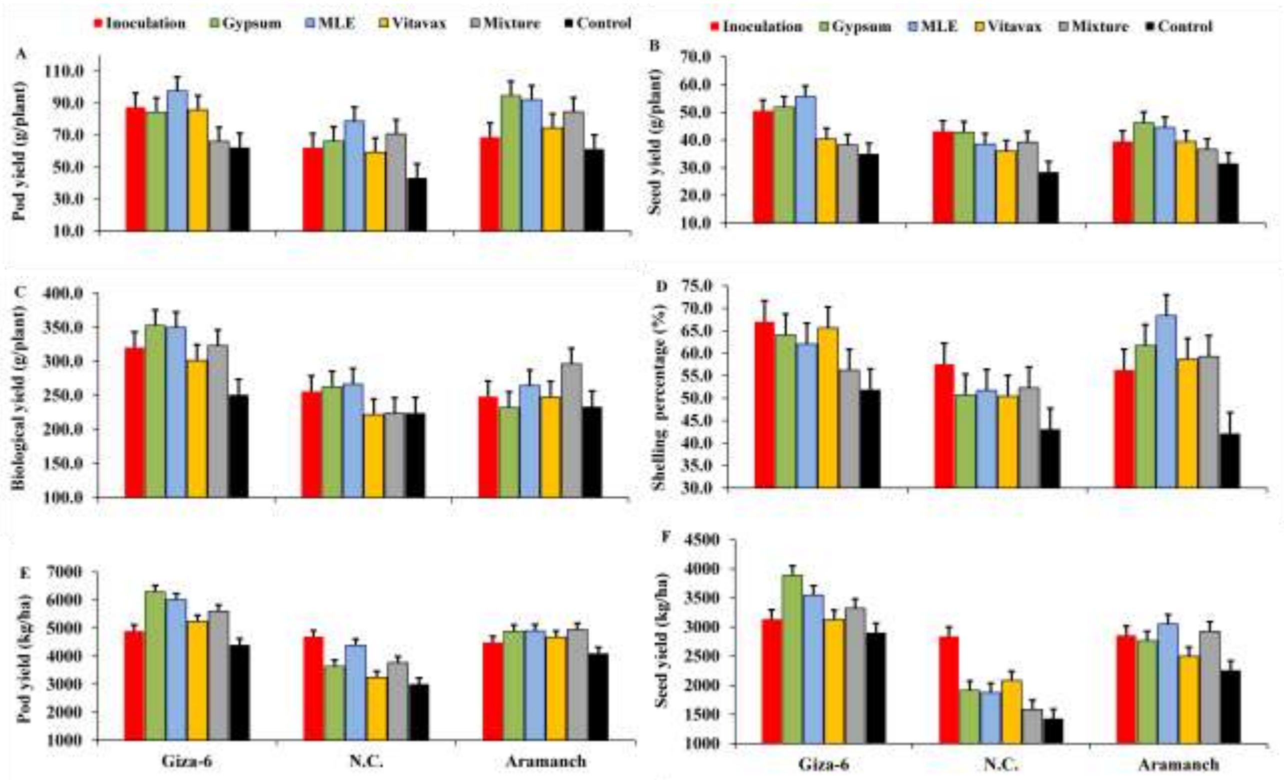

Figure 2. Impact of seed treatments on pods yield per plant (A), seed yield per plant (B), biological yield per plant (C), shelling percentage (D), pod yield per hectare (E), and seed yield per hectare (F) of three peanut cultivars. The bars on the columns represent the HSD (*P* < 0.05).

Respecting the influence of seed treatments on pod yield per plant, moringa extract, followed by gypsum and vitavax, possessed the heaviest pod yield per plant (Table 3). Likewise, the highest weight of seeds per plant resulted from gypsum and moringa extract, followed by *Rhizobium* inoculation. Furthermore, moringa extract possessed the highest dry weight per plant, followed by gypsum. The highest shelling percentage of peanut occurred from *Rhizobium* inoculation and moringa extract, followed by gypsum and vitavax. Moringa extract, followed by gypsum and *Rhizobium* inoculation, showed the uppermost pod yield. The highest seed yield resulted using *Rhizobium* inoculation, followed by gypsum and moringa extract applications (Table 3). Results of the interaction effect between peanut cultivars and seed treatment indicated the superiority of Giza-6 treated with *Rhizobium* inoculation, gypsum, and moringa extract, followed by Aramanch treated with gypsum and moringa extract, in producing pod yield per plant (Figure 2). Inversely, the lowest value came from the untreated three cultivars. Giza-6 treated with gypsum, *Rhizobium* inoculation, and moringa extract displayed the highest seed yield per plant. Additionally, Giza-6 treated with *Rhizobium* inoculation, gypsum, and moringa extract, as well as, Aramanch treated with moringa extract, provided the highest biological yield per plant.

Quality traits

The assessed peanut cultivars, seed treatments, and their interaction demonstrated a highly notable influence on crude protein content, crude protein yield, oil content, and oil yield (Table 4). Giza-6 and N.C. recorded the highest crude protein content, while Giza-6 and Aramanch produced the highest crude protein yield, oil content, and oil yield (Table 4). Concerning the influence of seed treatments, *Rhizobium* inoculation, gypsum, and moringa extract displayed the highest crude protein content, crude protein yield, oil content, and oil yield. The interaction between peanut cultivars and seed treatments indicates the superiority of Giza-6 and N.C. treated by most applications in crude protein content (Figure 3). Similarly, Giza-6 treated with the most applications displayed the highest crude protein yield. N.C. treated with moringa extract recorded the highest oil content. The highest oil yield came from Giza-6 treated with *Rhizobium* inoculation, gypsum, and moringa extract.

The evaluated peanut cultivars exhibited highly significant differences in yield and quality traits. These findings indicated the existence of genetic variability in the assessed cultivars, which need exploiting for developing high-yielding genotypes (Igartua *et al.*, 2015; Salem *et al.*, 2020; Kamara *et al.*, 2021b; ElShamey *et al.*, 2022a). Similarly, Puangbut *et al.* (2009), Dang *et al.* (2013), El-Far *et al.*

Table 4. Influence of different seed treatments on crude protein content, crude protein yield, oil content, and oil yield of three peanut cultivars.

Studied factor	Crude protein content (%)	Crude protein yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)
Cultivars (C)				
Giza-6	25.21^{a}	843.3^{a}	33.71^{c}	1147^{a}
N.C.	25.78^{a}	535.7^{c}	34.64^{b}	706.5^{c}
Aramanch	23.89^{b}	638.1^{b}	35.42^{a}	944.7^{b}
Seed Treatments (S)				
Inoculation	24.65^{b}	726.4^{a}	34.97^{b}	1028.1^{a}
Gypsum	26.99^{a}	767.8^{a}	35.69^{a}	1024.2^{a}
MLE*	26.78^{a}	739.3^{a}	34.05^{b}	946.9^{b}
Vitavax	24.05^{b}	623.3^{b}	36.32^{a}	928.7^{b}
Control	22.32^{c}	505.2^{c}	31.91^{c}	735.1^{c}
ANOVA				
Cultivars (C)	< 0.001	< 0.001	< 0.001	< 0.001
Seed Treatments (S)	< 0.001	< 0.001	< 0.001	< 0.001
C×S	< 0.001	< 0.001	< 0.001	< 0.001

*MLE: Moringa seed extract

Means followed by different letters under the cultivars or seed treatments are significantly different by Tukey's HSD test at $P \leq 0.05$.

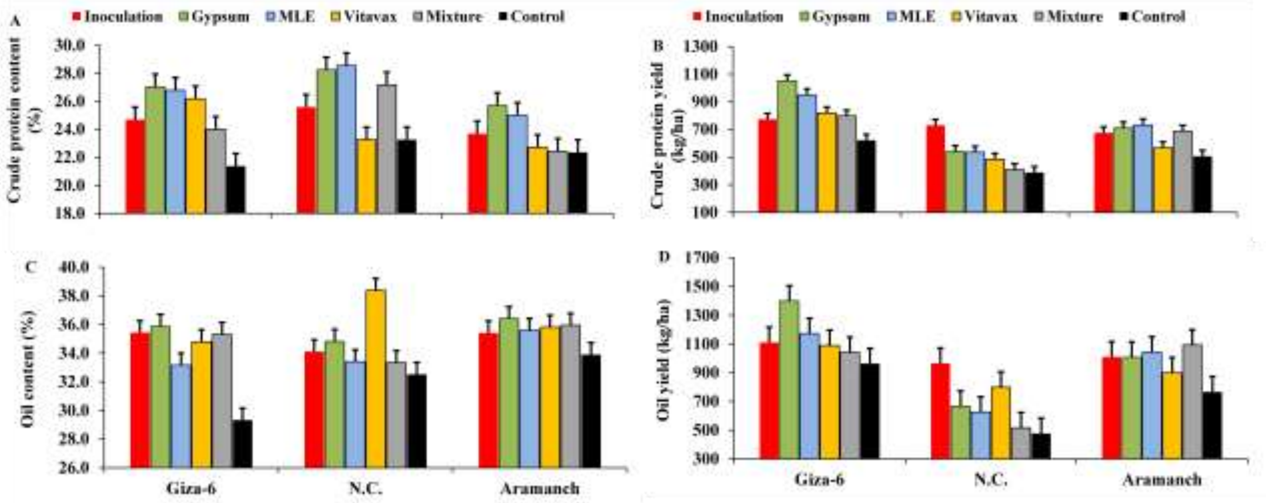

Figure 3. Impact of seed treatments on crude protein content (A), crude protein yield (B), oil content (C), and oil yield (D), of three peanut cultivars. The bars on the columns represent the HSD ($P < 0.05$).

(2016), Ajay *et al.* (2020), Patel *et al.* (2021), and Wang *et al.* (2022) demonstrated significant differences among peanut genotypes. The applied treatments, *Rhizobium* inoculation, gypsum, moringa extract, and vitavax, considerably helped enhance all evaluated agronomic and quality traits compared with the untreated control. *Rhizobium* inoculation exhibited positive influences on yield attributes. In this respect, Radwan (2017) depicted that inoculation fixes atmospheric nitrogen, solubilizes phosphate, synthesizes growth-promoting substances, and boosts the decomposition of plant residues Accordingly, *Rhizobium* inoculation improves soil fertility, which aids plant growth and productivity, particularly in low-fertility soils in arid regions. Gypsum displayed boosting influence on the yield and quality traits of peanuts. In this context, Gashti *et al.* (2012) elucidated that gypsum has a high solubility in the soil and causes easy release and availability of calcium content. Moreover, Kadirimangalam *et al.* (2022) deduced that gypsum positively impacts the absorption of various nutrients, such as, sulfur and phosphorus, which possess vital roles in peanut growth and seed yield. Besides, gypsum plays a crucial role in seed setting, fertility of peanuts, and increasing seed size, which reflects its impact on yield traits (Arnold *et al*., 2017; Hendrix *et al*., 2020; Laxmanarayanan *et al*., 2020). Thus, it was one of the best treatments for enhancing yield attributes. Peanut is a sensitive crop of fungi causing pre- and postemergence damping-off (Mahmoud *et al*., 2013). Therefore, the seeds are treated with chemical fungicides to avoid stand losses in commercial peanut production. In this connection, Ruark and Shew (2010), Hassuba *et al.* (2016), and El-Bably *et al.* (2018) demonstrated the ability of the vitavax to enhance emergence and seedling survival compared with untreated seed. Moringa extract contains various nutrients, antioxidants, and phytohormones (Nasir *et al*., 2016). Furthermore, the seed treatment moringa extract could serve as a potential alternative to fungicides (El-Mohamedy and Abdalla, 2014). Consequently, moringa extract confirmed a positive impact on yields and quality traits of peanuts.

Interrelationship among the evaluated treatments and traits

Understanding the interrelationship between the assessed treatments and traits is a vital aspect that can provide valuable information (Kamara *et al*., 2021c; ElShamey *et al*., 2022b; Omar *et al*., 2022; Boudiar *et al*., 2022). The heatmap is an appropriate statistical procedure to study the association among investigated treatments and traits. Employing the heatmap explored the interrelationship among studied treatments and traits in various published reports (Mansour *et al*., 2020; Moustafa *et al*., 2021; Mannan *et al*., 2022). In the latest study, the heatmap and hierarchical clustering based on

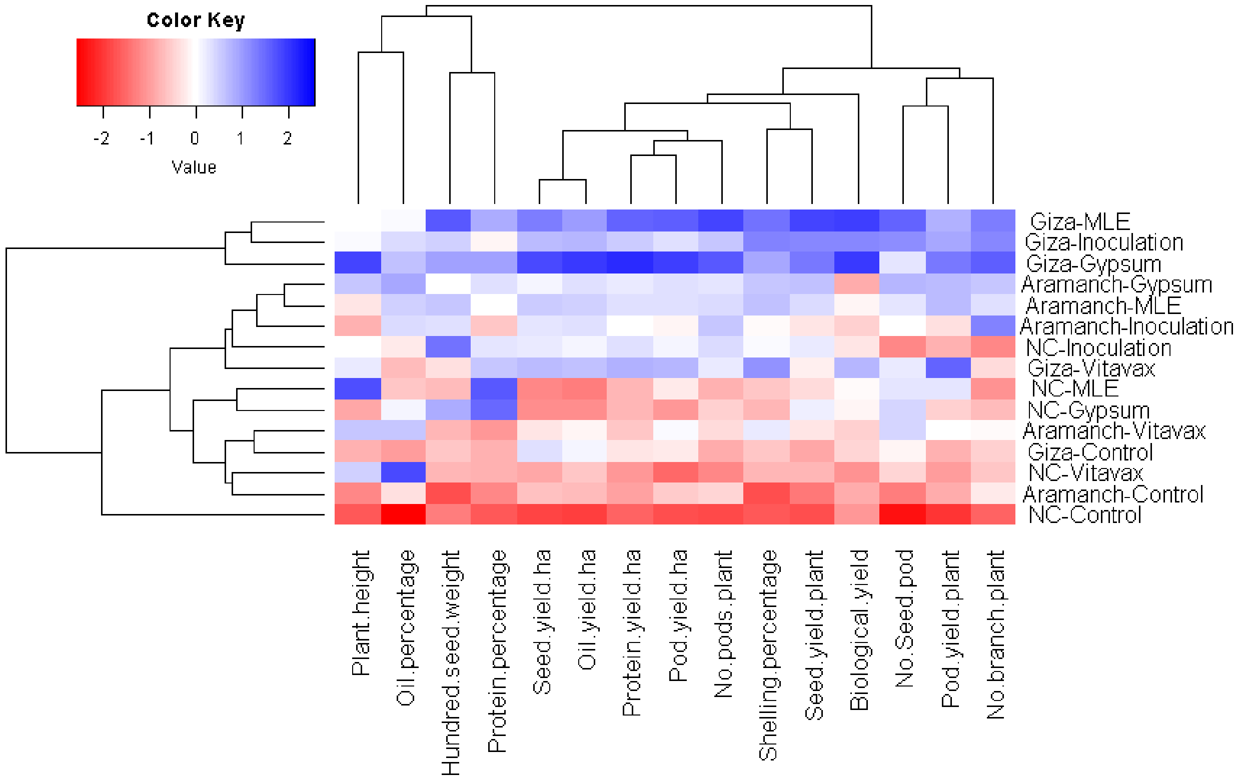

Figure 4. Heatmap and hierarchical clustering divide the assessed peanut cultivars and seed treatments into different clusters based on agronomic and quality traits. Blue and red colors indicate high and low values for the corresponding traits, respectively.

the studied agronomic and quality traits divided the assessed cultivars and seed treatments into different clusters (Figure 4). Giza-6 treated with moringa extract, *Rhizobium* inoculation, and gypsum possessed the highest values for most evaluated traits (depicted in blue). On the contrary, untreated control in the three cultivars had the lowest values (depicted in red).

CONCLUSIONS

The evaluated peanut cultivars displayed significant differences in yield and quality traits. It reveals the existence of genetic variability in the evaluated cultivars, which needs exploiting for developing high-yielding genotypes. Giza-6 and Aramanch proved superior cultivars and exhibited the highest values of studied yield and quality traits. The assessed seed treatments substantially enhanced peanut yield traits, oil, and protein content of peanuts showing the superiority of *Rhizobium* inoculation, gypsum, and moringa extract.

REFERENCES

Aderiye KO, Kehinde TO, Adetumbi JA, Ogunniyan DJ, Adebisi MA (2021). Response of groundnut (*Arachis hypogaea* L.) genotypes to accelerated aging treatment. *Not. Sci. Biol.* 13: 10833-10833**.**

Ajay B, Bera S, Singh A, Kumar N, Gangadhar K, Kona P (2020). Evaluation of genotype × environment interaction and yield stability analysis in peanut under phosphorus stress condition using stability parameters of AMMI model. *Agric. Res*. 9: 477-486**.**

Ali S, Ahmad R, Hassan MF, Ibrar D, Iqbal MS, Naveed MS, Arsalan M, Rehman A, Hussain T (2022). Groundnut genotypes' diversity assessment for yield and oil quality traits through multivariate analysis. *SABRAO J. Breed. Genet*. 54(3): 565-573. http://doi.org/10.54910/sabrao2022.54.3.9.

Arnold JA, Beasley JP, Harris GH, Grey TL, Cabrera M (2017). Effect of gypsum application rate, soil type, and soil calcium on yield, grade, and seed quality of runner-type peanut cultivars. *Peanut Sci*., 44: 13-18.

Ashraf M, Foolad M (2005). Pre-sowing seed treatment: A shotgun approach to improve germination, plant growth, and crop yield under saline and non-saline conditions. *Adv. Agron.* 88: 223-271.

Bera SK, Kamdar JH, Kasundra SV, Patel SV, Jasani MD, Maurya A, Dash P, Chandrashekar AB, Rani K, Manivannan N (2019). Steady expression of high oleic acid in peanuts bred by marker-assisted backcrossing for fatty acid desaturase mutant alleles and its effect on seed germination along with other seedling traits. *PloS one* 14, e0226252.

Bogino P, Banchio E, Rinaudi L, Cerioni G, Bonfiglio C, Giordano W (2006). Peanut (*Arachis hypogaea*) response to inoculation with *Bradyrhizobium* sp. in soils of Argentina. *Ann. Appl. Biol*. 148: 207-212.

Boudiar R, Alshallash KS, Alharbi K, Okasha SA, Fenni M, Mekhlouf A, Fortas B, Hamsi K, Nadjem K, Belagrouz A, Mansour E (2022). Influence of tillage and cropping systems on soil properties and crop performance under semi-arid conditions. *Sustainability.* 14: Article number 11651.

Cantonwine E, Holbrook C, Culbreath A, Tubbs R, Boudreau M (2011). Genetic and seed treatment effects in organic peanut. *Peanut Sci*. 38, 115-121.

Carvalho MJ,Vorasoot N, Puppala N, Muitia A, Jogloy S (2018). Effects of terminal drought on growth, yield and yield components in valencia peanut genotypes. *SABRAO J. Breed. Genet.* 49(3): 270-279.

Dang PM, Chen CY, Holbrook CC (2013). Evaluation of five peanuts (*Arachis hypogaea*) genotypes to identify drought-responsive mechanisms utilizing candidate-gene approach. *Funct. Plant Biol*. 40: 1323-1333.

Desoky E-SM, Mansour E, Ali MMA, Yasin MAT, Abdul-Hamid MIE, Rady MM, Ali EF (2021). Exogenously used 24-epibrassinolide promotes drought tolerance in maize hybrids by improving plant and water productivity in an arid environment. *Plants* 10: 354.

El-Bably H ,Abdel-Monaim M, El-Sayed S (2018). Effectiveness of bio-control agents and essential oils on controlling damping-off disease in peanut plants. *Egyptian J. Phytopathol.* 46: 165-177.

El-Far I, Ali E, El-Sawy W, Mohamed A (2016). Evaluation of some peanut genotypes under two planting methods and different fertilization levels. *Assiut J. Agric*. Sci. 47: 311-324.

El-Hady A, Mohamed A, Abd-Elkrem YM, Rady MO, Mansour E, El-Tarabily KA, AbuQamar SF, El-Temsah ME (2022). Impact on plant productivity under low fertility sandy soil in the arid environment by the revitalization of lentil roots. *Front. Plant Sci*. Article number 2668.

El-Mohamedy RS, Abdalla AM (2014). Evaluation of the antifungal activity of *Moringa oleifera* extracts as a natural fungicide against some plant pathogenic fungi *in vitro. J. Agric. Sci. Technol*. 10: 963-982.

El-Sanatawy AM, Ash-Shormillesy SMAI, Qabil N, Awad MF, Mansour E (2021a). Seed halo-priming improves seedling vigor, grain yield, and water use efficiency of maize under varying irrigation regimes .*Water* 13: 2115.

El-Sanatawy AM, El-Kholy ASM, Ali MMA, Awad MF, Mansour E (2021b). Maize seedling establishment, grain yield and crop water productivity response to seed priming and irrigation management in a Mediterranean arid environment. *Agronomy* 11: 756.

ElShamey EA, Sakran RM, ElSayed MA, Aloufi S, Alharthi B, Alqurashi M, Mansour E, Abd El-Moneim D (2022a). Heterosis and combining ability for floral and yield characters in rice using cytoplasmic male sterility system. *Saudi J. Biol. Sci.* 29: 3727-3738.

ElShamey EAZ, Hamad HS, Alshallash KS, Alghuthaymi MA, Ghazy MI, Sakran RM, Selim ME, ElSayed MAA, Abdelmegeed TM, Okasha SA, Behiry SI, Boudiar R, Mansour E (2022b). Growth regulators improve the outcrossing rate of diverse rice cytoplasmic male sterile lines through affecting floral traits. *Plants* 11: 1291.

FAOSTAT (2022). Food and Agriculture Organization of the United Nations. Statistical Database. Available online: http://www.fao.org/faostat/en/#data (accessed on 30 August 2022).

Gashti AH, Vishekaei MNS, Hosseinzadeh MH (2012). Effect of potassium and calcium application on yield, yield components and qualitative characteristics of peanut (*Arachis hypogaea* L.) in Guilan Province, Iran. *World Appl. Sci*. J 16: 540-546.

Gharib MAA, Qabil N, Salem AH, Ali MMA, Awaad HA, Mansour E (2021). Characterization of wheat landraces and commercial cultivars based on morpho-phenological and agronomic traits. *Cereal Res. Commun.* 49: 149-159.

Gracia MP, Mansour E, Casas AM, Lasa JM, Medina B, Molina-Cano JL, Moralejo MA, López A, López-Fuster P, Escribano J, Ciudad FJ, Codesal P, Montoya JL, Igartua E (2012). Progress in the Spanish national barley breeding program. *Span. J. Agric. Res*. 10: 741.

Habibullah M, Sarkar S, Islam MM, Ahmed KU, Rahman MZ, Awad MF, ElSayed AI, Mansour E, Hossain MS (2021). Assessing the response of diverse sesame genotypes to waterlogging durations at different plant growth stages. *Plants.* 10: Article number 2294.

Hassuba M, El-Kholy R, El-Samadisy A, Helalia A (2016). Evaluation of seed treatments with fungicides and bioagents in controlling peanut diseases. *J. Plant Prot. Pathol*. 7, 695-700.

Hendrix MC, Obed IL, Alice MM, Elijah P, Jones Y, Samuel CN, Rick B (2020). The effects of gypsum on pod yield and pre-harvest aflatoxin contamination in selected peanut cultivars of Zambia. *Afr. J. Plant Sci.* 14: 134-138.

Igartua E, Mansour E, Cantalapiedra CP, Contreras-Moreira B, Gracia MP, Fuster P, Escribano J, Molina-Cano JL, Moralejo M, Thomas WT, Karsai I (2015). Selection footprints in barley breeding lines detected by combining genotyping-by-sequencing with reference genome information. *Mol. Plant Breed*. 35: 1-14.

Jadon K, Thirumalaisamy P, Kumar V, Koradia V, Padavi R (2015). Management of soil-borne diseases of groundnut through seed dressing fungicides. *Crop Prot*. 78: 198-203**.**

Javanmardi F, Khodaei D, Sheidaei Z, Bashiry M, Nayebzadeh K, Vasseghian Y, Mousavi Khaneghah A (2022). Decontamination of aflatoxins in edible oils: A comprehensive review. *Food Rev. Int*. 38: 1410-1426**.**

Kadirimangalam SR, Sawargaonkar G, Choudhari P (2022). Morphological and molecular insights of calcium in peanut pod development. *J. Agric. Food Res.* 9: 100320**.**

Kamara MM, Ghazy NA, Mansour E, Elsharkawy MM, Kheir AM, Ibrahim KM (2021a). Molecular genetic diversity and line × tester analysis for resistance to late wilt disease and grain yield in maize. *Agronomy*. 11: Article number 898.

Kamara MM, Ghazy NA, Mansour E, Elsharkawy MM, Kheir AM, Ibrahim KM (2021b). Molecular genetic diversity and line × tester analysis for resistance to late wilt disease and grain yield in maize. *Agronomy.* 11: Article number 898.

Kamara MM, Ibrahim KM, Mansour E, Kheir AM, Germoush MO, Abd El-Moneim D, Motawei MI, Alhusays AY, Farid MA, Rehan M (2021c). Combining ability and gene action controlling grain yield and its related traits in bread wheat under heat stress and normal conditions. *Agronomy.* 11: Article number 1450.

Kamara MM, Rehan M, Mohamed AM, El Mantawy RF, Kheir AM, Abd El-Moneim D, Safhi FA, ALshamrani SM, Hafez EM, Behiry SI, Ali MM (2022). Genetic potential and inheritance patterns of physiological, agronomic, and quality traits in bread wheat under normal and water deficit conditions. *Plants.* 11: Article number 952.

Khetrin SM, Paula AMdL, Fernando ZM, Simone dPCBM, Vinicius AC, Caroline MM, Jose GBM, Patricia AC, Rodrigo SA, Jose CL (2018). Physiological quality of bean genotypes seeds peanut and xamego treated with fungicides and insecticides. *Afr. J. Agric. Res*. 13: 82-89**.**

Kolde R (2019). Pheatmap: Pretty Heatmaps. R package version 1.0. 12. CRAN. R-project. org/package= pheatmap.

Koolachart R, Jogloy S, Vorasoot N, Wongkaew S, Holbrook CC, Jongrungklang N, Kesmala T, Suriharn B (2019). Association of aflatoxin contamination and root traits of peanut genotypes under terminal drought. *SABRAO J. Breed. Genet.* 51(3): 234-251.

Laxmanarayanan M, Prakash NB, Dhumgond P, Ashrit S (2020). Slag-based gypsum as a source of sulphur, calcium, and silicon and its effect on soil fertility and yield and quality of groundnut in Southern India. *J. Soil Sci. Plant Nutr*. 20: 2698-2713.

Li Y, Zhang R, Qin X, Liao Y, Siddique KH (2018). Changes in the protein and fat contents of peanut (*Arachis hypogaea* L.) cultivars released in China in the last 60 years. *Plant Breed*. 137: 746-756**.**

Mahmoud EY, Ibrahim MM, Essa TAA (2013). Efficacy of plant essential oils in controlling damping–off and root rots diseases of peanut as fungicides alternative. *J. Appl. Sci. Res*. 9: 1612-1622.

Mahrous NM, Safina SA, Abo-Taleb H, El-Sayed El-Behlak S (2015). Integrated use of organic, inorganic, and biofertilizers on yield and quality of two peanuts (*Arachis hypogaea* L.) cultivars grown in sandy saline soil. *Am-Eurasian J. Agric. Environ. Sci*. 15: 1067-1074**.**

Mannan MA, Tithi MA, Islam MR, Al Mamun MA, Mia S, Rahman MZ, Awad MF, ElSayed AI, Mansour E, Hossain MS (2022). Soil and foliar applications of zinc sulfate and iron sulfate alleviate the destructive impacts of drought stress in wheat. Cereal Res. Commun**.** doi.org/10.1007/s42976-022-00262-5.

Mansour E, Mahgoub HAM, Mahgoub SA, El-Sobky E-SEA, Abdul-Hamid MI, Kamara MM, AbuQamar SF, El-Tarabily KA, Desoky E-SM (2021a). Enhancement of drought tolerance in diverse *Vicia faba* cultivars by inoculation with plant growth-promoting rhizobacteria under newly reclaimed soil conditions. *Sci. Rep*. 11:24142.

Mansour E, Moustafa ES, Abdul-Hamid MI, Ash-shormillesy SM, Merwad ARM, Wafa HA, Igartua E (2021b). Field responses of barley genotypes across a salinity gradient in an arid Mediterranean environment. *Agric. Water Manag*. 258: Article number 107206.

Mansour E, Moustafa ESA, Desoky E-SM, Ali MMA, Yasin MAT, Attia A, Alsuhaibani N, Tahir MU, El-Hendawy S (2020). Multidimensional evaluation for detecting salt tolerance of bread wheat genotypes under actual saline field growing conditions. *Plants* 9: 1324**.**

Moustafa ESA, El-Sobky E-SEA, Farag HIA, Yasin MAT, Attia A, Rady MOA, Awad MF, Mansour E (2021). Sowing date and genotype influence on yield and quality of dual-purpose barley in a salt-affected arid region. *Agronomy* 11: 717**.**

Naab J, Tsigbey F, Prasad P, Boote K, Bailey J, Brandenburg R (2005). Effects of sowing date and fungicide application on yield of early and late maturing peanut cultivars grown under rainfed conditions in Ghana. *Crop Prot*. 24: 325-332**.**

Nasir M, Khan AS, Basra SA, Malik AU (2016). Foliar application of moringa leaf extract, potassium, and zinc influence the yield and fruit quality of 'Kinnow' mandarin. *Sci. Hortic.*210: 227-235.

Nayak SN, Hebbal V, Bharati P, Nadaf HL, Naidu GK, Bhat RS (2020). Profiling of nutraceuticals and proximates in peanut genotypes differing for seed coat color and seed size. *Front. Nutr*. 7: 45**.**

Nazarov PA, Baleev DN, Ivanova MI, Sokolova LM, Karakozova MV (2020). Infectious plant diseases: Etiology, current status, problems and prospects in plant protection. *Acta Nat*. 12: 46**.**

Nwangburuka C, Oyekale K, Ezekiel C, Anokwuru P, Badaru O (2012). Effects of *Moringa oleifera* leaf extract and sodium hypochlorite seed pre-treatment on seed germination, seedling growth rate, and fungal abundance in two accessions of *Abelmoschus esculentus* (L) Moench. *Arch. Appl. Sci. Res*. 4: 875-881**.**

Omar M, Rabie HA, Mowafi SA, Othman HT, El-Moneim DA, Alharbi K, Mansour E, Ali MM (2022). Multivariate analysis of agronomic traits in newly developed maize hybrids grown under different agro-environments. *Plants.* 11: Article number 1187.

Patel M, Fatnani D, Parida AK (2021). Silicon-induced mitigation of drought stress in peanut genotypes (*Arachis hypogaea* L.) through ion homeostasis, modulations of the antioxidative defense system, and metabolic regulations. *Plant Physiol. Biochem*. 166: 290-313**.**

Ponce-Molina LJ, Casas AM, Pilar Gracia M, Silvar C, Mansour E, Thomas WB, Schweizer G, Herz M, Igartua E (2012). Quantitative trait loci and candidate loci for heading date in a large population of a wide barley cross. *Crop Sci.* 52: 2469-2480.

Popoola JO, Aworunse OS, Ojuederie OB, Adewale BD, Ajani OC, Oyatomi OA, Eruemulor DI, Adegboyega TT, Obembe OO (2022). The exploitation of orphan legumes for food, income, and nutrition security in Sub-Saharan Africa*. Front. Plant Sci*. 13: 782140**.**

Prakash NB, Dhumgond P, Ashrit S (2020). Slag-based gypsum as a source of sulphur, calcium, and silicon and its effect on soil fertility and yield and quality of groundnut in Southern India. *J. Plant. Nutr* **.***Soil Sci.* 20: 2698-2713**.**

Puangbut D, Jogloy S, Vorasoot N, Akkasaeng C, Kesmalac T, Patanothai A (2009). Variability in yield responses of peanut (*Arachis hypogaea* L.) genotypes under early season drought. *Asian J. Plant Sci*. 8: 254-264**.**

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Radwan TED (2017). Evaluation of elemental sulphur application with *Rhizobia* inoculation on peanut yield and its quality grown in sandy soil at Egypt. *Egypt. J. Bot*. 57: 217-240**.**

Rashmi I, Mina B, Kuldeep K, Ali S, Kumar A, Kala S, Singh R (2018). Gypsum-an inexpensive, effective sulphur source with multitude impacts on oilseed production and soil quality-A review. Agric. Rev. 39: 1-8**.**

Rocha I, Ma Y, Souza-Alonso P, Vosátka M, Freitas H, Oliveira RS (2019). Seed coating: A tool for delivering beneficial microbes to agricultural crops. *Front. Plant Sci*. 10, 1357**.**

Ruark S, Shew B (2010). Evaluation of microbial, botanical, and organic treatments for control of peanut seedling diseases. *Plant Dis*. 94: 445-454**.**

Sakran RM, Ghazy MI, Rehan M, Alsohim AS, Mansour E (2022). Molecular genetic diversity and combining ability for some physiological and agronomic traits in rice under well-watered and water-deficit conditions. *Plants*, 11: Article number 702.

Salem TSG, Rabie HA, Mowafy SAE, Eissa AEM, Mansour E (2020). Combining ability and genetic components of Egyptian cotton for earliness, yield, and fiber quality traits*. Sabrao J. Breed. Genet*. 52: 369-389.

Selem E, Hassan AA, Awad MF, Mansour E, Desoky ESM (2022). Impact of exogenously sprayed antioxidants on physio-biochemical, agronomic, and quality parameters of potato in salt-affected soil. *Plants.* 11: Article number 210.

Swailam M, Mowafy S, El-Naggar NZ, Mansour E (2021). Agronomic responses of diverse bread wheat genotypes to phosphorus levels and nitrogen forms in a semiarid environment. *Sabrao J. Breed. Genet*. 53: 592-608.

Wang X, Chen CY, Dang P, Carter J, Zhao S, Lamb MC, Chu Y, Holbrook C, Ozias-Akins P, Isleib TG (2022). Variabilities in symbiotic nitrogen fixation and carbon isotope discrimination among peanut (*Arachis hypogaea* L.) genotypes under drought stress. *J. Agron. Crop Sci*. 22: 1-14**.**

Yin H, Li Y-T, Tsai W, Dai H, Wen H (2022). An immunochromatographic assay utilizing magnetic nanoparticles to detect major peanut allergen Ara h 1 in processed foods. *Food Chem.* 375: 131844.