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Effect of Nano-Fertilizer and Bio-Growth Regulator on Yield Attributes of Wheat

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ABSTRACT

This work aimed at examining the influence of foliar spraying with nano-nitrogen fertilizer (Nano- N- 0, 250, and 500 mg/L) and salicylic acid (SA- 0, 100, and 200 mg/L) on yield attributes of wheat. The experiments were conducted in a randomized complete block design (RCBD) using split plot arrangement with 3-replication and conducted during the two winter seasons of 2021/2022 and 2022/2023. Results revealed that Nano-N had a remarkable influence on improving the No. of tillers/m^2, No. of grain/spike, and grain, straw, and biological yield of wheat compared to control ($p < 0.05$), observably under high concentration (500 mg/L). The highest positive effect of SA application on yield attributes of wheat was observed at 200 mg/L. Most importantly, the interaction between Nano-N at 500mg/L and SA at 200 mg/L considerably increased the straw, grain, and biological yield (7719, 6648, and 14367 kg/ha, respectively) relative to control and/or other treatments ($p < 0.05$), whereas the maximal harvest index was observed for untreated plants [0 (Nano-N) x 0 mg/L (SA)]. Further, correlational analysis demonstrated that grain yield had positive/ direct interrelationship with No. of tillers/m^2 (r= 0.75), No. of spikelet's (r= 0.70), spike length (r= 0.85), and No. of grains/spike (r= 0.69), whereas the increase of plant height strongly contributed to the enhancement of biological yield by 86%. The current outcomes, accordingly, provide important information to the farmers about the optimum practical application of Nano-N and SA (at 500 x 200 mg/L) to maximize wheat production.

***Keywords*:** wheat, foliar spraying, nano-fertilizers, salicylic acid, yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.), a major food crop in the world, is cultivated widely on five continents (Africa, Asia, South and North America, and Europe) with production of 770.88 Mt in 2021 (FAO, 2023). It is basically used as a food source for around 40% of the global population (Acevedo *et al.*, 2018), providing 20% of daily calories and proteins (Alotaibi *et al.*, 2023). The climatic changes and the continuously increasing population, however, have lately brought new challenges in wheat shortage, food security and sustainability. Enhancing wheat yield by adjusting the agricultural policies (e.g., fertilization practices), therefore, is a substantial goal in agricultural research, particularly in the developing countries (such as Egypt). Unfortunately, local farmers usually depend on excessive use of chemical fertilizers to maximize economic benefits and wheat yield, causing reduction in soil fertility (Hu *et al*, 2021). Moreover, long-term overuse of such fertilizers causes soil degradation and acidification, as well as reduces soil nutrients and fertilizer use efficiencies, leading to environmental issues (Haj-Amor *et al.*, 2022). Accordingly, researchers have recently tended to explore the possibility of applying nanotechnology, as a new technique in form of nano fertilizers, in the agricultural field to eliminate the limitation of traditional (i.e., chemical) fertilizers and improve the crop productivity.

Nano-fertilizers have been indicated in previous reports to have plausible advantages relative to conventional fertilizers in improving growth attributes (e.g., leaf area, plant height, No. of leaves/plant), efficiency of nutrients, chlorophyll content, and photosynthesis rate (Ali and Al-Juthery, 2017; Yadegari, 2013), resulting in increased economic crop yield with better quality (Lakshmi, 2017). These improvements are mainly attributable to the possibility of nano-particles to bind with protein carrier and the penetrate the plant tissues, enhancing the mass transfer of nano-materials among cells (AL-Taey *et al.*, 2021; Morales-Diaz *et al.*, 2017). Also, the application of such fertilizers can reduce the potential adverse impacts and soil contamination when traditional fertilizers are applied (Monreal, 2015; Elemike *et al.*, 2019). Meena *et al.* (2021 realized that the maximal No. of tillers/meter (80.16), straw yield (7135.46 kg/ha), and grain yield (5565.20kg/ha) were noted following spraying of Nano-Zn at 14 + 28 days after planting (DAP). Furthermore, Al-Juthery et al. (2018) found that spraying of tri-nano N+P significantly improved spike length, plant height, chlorophyll content, and K, P, and N content in leaves of wheat (11.66 cm, 81.55 cm, 55%, 2.66%, 0.6%, and 2.88%) respectively.

On the other hand, salicylic acid (SA) has a key effect in the controlling of various physiological processes throughout plant (e.g., wheat) growth/ development including ion adsorption, germination, and photosynthesis, depending on the growth period, concentration used as well as environmental conditions (Singh and Usha, 2015; Iqbal *et al.*, 2006). Ibrahim *et al.* (2014) illustrated that the use of SA (50, 100 mg/L) remarkably increased weight of 1000-grain, No. of spikelet's/spike, harvest index, No. of spikes/m^2, and straw, grain, and biological yield of wheat compared with control. Also, Abdel-Lattif *et al.* (2019) indicated that foliar spraying of SA (100 mg/L) on wheat resulted in the maximum values of plant height (101.28 cm), weight of 100-grain (5.29 g), spike weight per plant (10.15 g), No. of grains per plant

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(163.22), and grain weight per plant (8.14 g). Further, EL-Nasharty *et al.* (2019) noticed that the growth traits i.e., shoot dry weight and plant height of wheat plants considerably enhanced following the foliar application of SA likened to control group.

Although some studies display that Nano-N and SA have already been applied to improve the productivity of some agricultural crops, however no information has previously been documented to explore their synergetic effects on the yield attributes of wheat. Motivated by such background, this study focused on the application of Nano-N fertilizer (0 – 500 mg/L) and SA (0 – 200 mg/L) on the No. of tillers/m^2, plant height, spike length, spike weight, No. of spikelet's, weight of 1000-grain, No. of grains/spike, and harvest index of wheat. Also, the straw, grain, and biological yield of wheat under varied experimental conditions were investigated. The existing outcomes will, therefore, be valuable in setting the technological data and fundamental information concerning the alterations in the yield characteristics of wheat for farmers.

MATERIALS AND METHODS

1. Investigational site and attributes

A field experiment of wheat cultivar Sakha 95 was conducted at the Research and Experimental Station, Fac. of Agric., Benha Univ., Qaluobia Governorate, Egypt, during the two seasons of 2021/2022 and 2022/2023. The experimental region was located at 45 m (an altitude) above sea height (31.10° E longitude and 30.45° N latitude). The split-plot experiment based on the RCBD with 3-replication was used in this research work. The main-plots involved three foliar spraying of Nano-N fertilizer. The sub-plots consisted of the foliar spraying of wheat with salicylic acid.

2. Experimental treatments

Three rates of Nano-N fertilizer (N_0= 0 (without Nano-N), N_1= 250, and N_2= 500 mg/L) were sprayed on wheat plants. Nano-N fertilizer, as a commercial product with particle sizing of 32.2 nm and absolute value of zeta potential of 54.8 mV (as displayed in Figure 1), was acquired from Nanotechnology Lab, Agricultural Research Centre, Giza, Egypt. Particle size distribution and zeta potential of Nano-fertilizer were analyzed using a Dynamic Light Scattering (Nano ZS-90, Malvern Instruments Ltd., UK) at 25 ± 1 °C. The Nano-fertilizer was diluted to around 500-folds (1/500) with deionized water before analysis. Salicylic acid (SA) was applied at three varied concentrations (SA_0 = 0 (without SA), SA_1 = 100, and SA_2 = 200 mg/L). The control group was sprayed with tap water. The SA product used in carrying out the experiments was bought from Algomhoria Chemical Company (Cairo, Egypt).

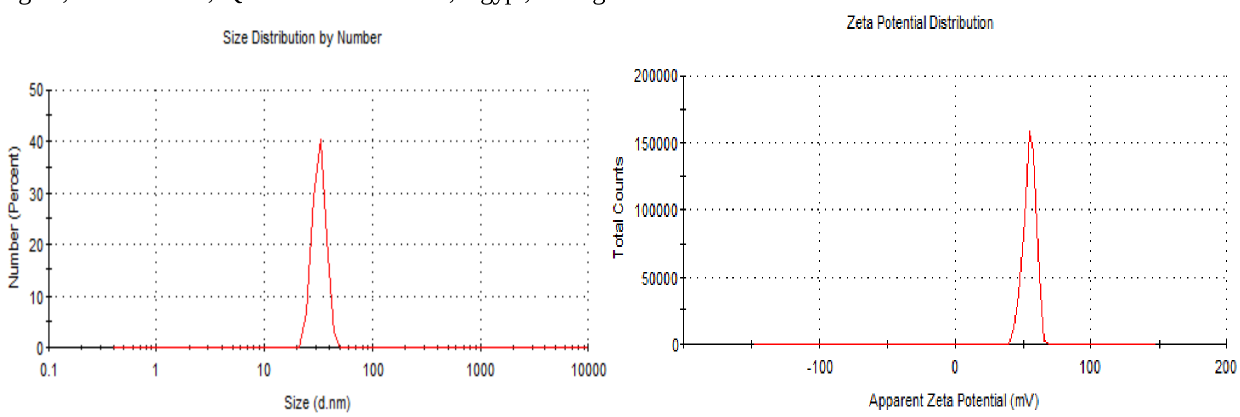

Figure 1. Particle sizing distribution and apparent zeta potential of Nano-N fertilizer.

Nano-N fertilizer was utilized at the beginning of flag leaf stage, whereas salicylic acid was sprayed at 30 DAP. The foliar application was conducted in the morning at 476.2 L/ha used for each plot by hand sprayer.

Chemical attributes of soil site (Table 1) were examined following the protocol of Jackson (1967). The chemical analysis of the investigational site (*i.e.*, organic matter, electrical conductivity, pH, soluble cations, soluble anions) was done during the two seasons before sowing wheat.

Table 1. Chemical attributes of experimental sites at 0- 0.4 m soil depth.

Properties		
EC (dSm^{-1})	**pH (1:2.5 w/v)**	**Organic matter (%)**
0.79	6.73	1.718
Soluble cations (mmolc L^{-1})		
Ca^{++}	K^+	
3.20	0.84	
Soluble anions (mmolcL^{-1})		
Cl^-	CO_3^{--}	HCO_3^-
1.65	0.00	3.55

3. Plant material and experimental conditions

Experimental field was ploughed, pulverized, and leveled to obtain smooth seed bed. Sakha 94 seeds were drilled in rows on November 25th and November 22nd in the first and second season, correspondingly. Wheat seeds were purchased from Field Crops Research Institute, Egypt. The preceding crop was maize in both seasons.

Nitrogen was added at 178.5 kg/ha in the form of ammonium nitrate (33.5%). Nitrogen fertilizer was utilized before the first irrigation (with equal amounts for all the plots). The remaining agronomic procedures (such as hand/ chemical weeding) were applied as needed. After sowing wheat, the remaining normal cultural treatments were practiced according to Ministry of Agriculture recommendations. Wheat plants were harvested on May in both successive seasons when the plants reached maturity.

4. Data collection and analysis

At maturity, a randomly selected plants from a chosen 1 m^2 in each plot were harvested and manually threshed as representative of the whole plot. The yield characteristics of wheat plants were quantified as follows:

a- Plant height was measured from 5 randomly chosen plants from the base to the top of spike by meter measure tape.

b- No. of tillers/ m^2 was randomly estimated from a selected unit area (1 m^2) in each plot.
c- Spike length was determined using a ruler from 5 spikes selected randomly from each plot at harvest.
d- No. of spikelet's/spike was counted from 5 randomly certain spikes.
e- No. of grains/spike was estimated using Automatic Seed Counter (Model: GA-234 A, Green Agritech Equipment Ltd., India) from the selected spikes and then averaged to record No. of grains per spike.
f- Spike weight (g) was quantified for the selected spikes using a Digital Electrical Balance (YHC weighing excellence, Wonderscales, China).
g- Weight of 1000-grain (g): four random samples of 1000-grain were taken from each plot, counted using Automatic Seed Counter, and afterward weighed using a Digital Electrical Balance.
h- Yield attributes (kg/ha): The straw, grain, and biological yield were computed from each plot and converted to kg/ha.
i- Harvest index was computed as a ratio amongst grain and biological yield and expressed in percent.

5. Statistical analysis

Data were analyzed with the aid of MSTAT software (MSTAT-C with MGRAPH V-21). Combined analysis was performed on the data of both seasons. Duncan's post-hoc was employed to compare the differences among means at $p<0.05$. Pearson's correlation and principal components analysis (PCA) were performed using Origin pro-2023b software (Origin Lab Corporation, MA, USA) to explore the relationships between yield attributes of wheat following different treatments. The coefficient of correlation (*r*) ranges from - 1 to 1. The higher the determined *r* value, the stronger the correlation. Generally, the correlation among various parameters is basically classified as weak (0 - 0.39), moderate (0.4 - 0.59), strong (0.6 - 1.0) (Oliveira *et al*., 2021).

RESULTS AND DISCUSSION

1. Plant height

Results illustrated that the differences among the two concentrations of Nano-N fertilizer (250 and 500 mg/L) were statistically significant compared with control (Figure 2). Maximum plant height (108.6cm) was noted at the concentration of 500 mg/L. On the other hand, minimum plant height was observed in control group (104.6 cm). Comparable observations were previously reported by Al-Juthery *et al.* (2018). These results were mainly due to the fact that the nanoparticles enhanced the nutrient efficiency, especially nitrogen, resulting in improving its readiness in the soil solution, which directly/positively contributed to enhanced growth and plant height (Hasan, and Saad, 2019). Furthermore, the plants sprayed with SA under varied concentrations (100, 200 mg/L) displayed significantly higher plant height over untreated plants ($p < 0.05$). The findings displayed that the maximal plant height (109.3 cm) was obtained when wheat was sprayed with SA at 200 mg/L, whereas the lowest plant height (104.0 cm) was noticed for control (without SA). Such outcome was linked to the activation of cell division and elongation of root cells after foliar application of SA, increasing the consumption of soluble carbohydrates to form young cell constituents, stimulating an improvement in plant growth and thereafter increased plant height (Simaei *et al*., 2012). The positive impact of SA on plant height was also indicated by Kareem *et al.* (2017). Remarkable increases were documented) in plant height of wheat after combined utilization of Nano-N and SA (p < 0.05, implying that plant height was influenced by the targeted treatments. Wheat plants sprayed with 500 x 200 mg/L (N_2S_2) were found to be significantly taller (112.1 cm) than the treated or untreated plants ($p < 0.05$). Nonetheless, the shortest plants (101.1 cm) were observed after the use of tap water (0 x 0 mg/L – N_0S_0). These observations were in good line with straw and biological yield (Figures 8B & C) of wheat in the existing work.

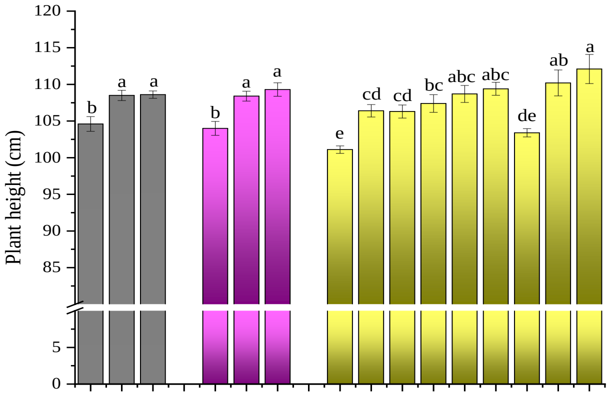

Figure 2. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the plant height of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

2. Number of tillers

Figure 3 shows the influence of spraying of Nano-N and SA on No. of tillers of wheat plants. The observation exhibited that the two concentrations of Nano-N fertilizer (250 and 500 mg/L) showed significant variations ($p < 0.05$) on the No. of tillers/m^2 during two-year of study when compared to plants sprayed with only tap water (control). However, no significant impact was noticed between 250 and 500 mg/L on the No. of tillers/m^2 of wheat plants. Maximum tillers (395.6 tiller/m^2) were found under spraying with Nano-N fertilizer at 500 mg/L followed by 250 mg/L. Both Nano-N concentrations (250 and 500 mg/L) observably increased the No. of tillers by 26.01 and 28.06%, respectively likened to control group (284.6). Such results could be explained by the potential effect of nitrogen as a main and essential nutrient in stimulating the tillering performance of wheat plants. These outcomes were supported by the findings of Wu (2013) who indicated that the increased No. of effective tillers/m^2 may be due to the reason that nano-NPK promoted plants to absorb water and nutrients from soil, resulting in enhancement of photosynthesis efficiency, which improved plant growth/ development and thus increased the No. of tillers. Furthermore, there were notable differences on No. of tillers ($p < 0.05$) following the spray of SA under varied concentrations (Figure 3). Obtained data showed that the SA at 200 ppm resulted the maximal value of No. of tillers/m^2 (396.1), whereas the minimal value (313.8) was observed from the 0 mg/L salicylic acid. The superiority may be ascribed to the role of the SA in enhancing the absorption percentage of some nutrients that have a substantial role in improving the growth/development of plants, which induced increment in the No. of tillers in the plant. On the other hand, the data of No of tillers/m^2 significantly varied due to the combined application of Nano-N and SA (Figure 3). The synergetic effect of Nano-N and SA at 500 mg/L and 200 mg/L resulted in the highest No of tillers/m^2, whilst the lowest value was noticed when the plants sprayed with Nano-N_0 and SA_{100} (i.e., 0 and 100 mg/L – N_0S_{100}).

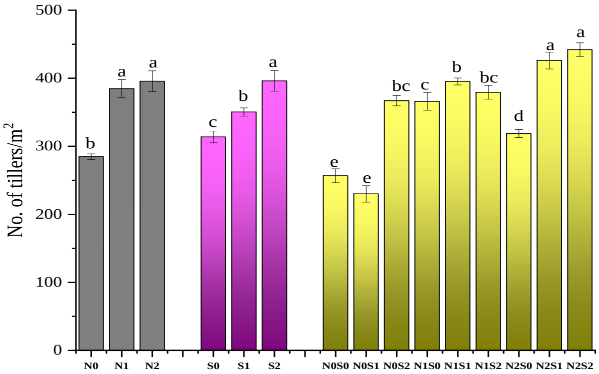

Figure 3. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the No. of tillers/m^2 of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

3. Spike length

The outcomes of spike length of treated plants with Nano-N fertilizer under varied concentrations are presented in Figure 4. The statistical conclusion of the results confirmed that the use of Nano-N fertilizer had non-significant ($p > 0.05$) impact on the spike length of wheat plants. The highest spike length was observed at 250 mg/L when compared to 500 mg/L Nano-N and control (without spraying of Nano-N). Similarly, Figure 4 indicates that there were no substantial variations ($p > 0.05$) among the low and high concentration of SA on the spike length of wheat plants. Nonetheless, the use of SA at 200 mg/L exhibited maximal value of the spike length relative to other concentration (0 and 100 mg/L). This phenomenon was possibly ascribed to the vigorous vegetative growth/ development of plants which ultimately increased leaf area and improved photosynthesis, thereby forming higher spike length (Lakhran *et al.*, 2021). Furthermore, the interaction amongst spraying of Nano-N fertilizer and SA had non-significant effect on spike length of wheat as presented in Figure 4.

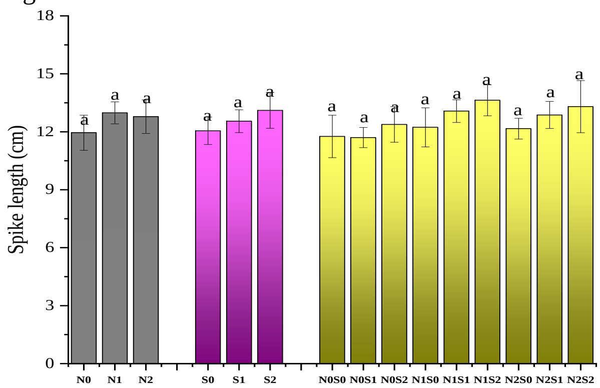

Figure 4. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the spike length of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

4. No. of spikelet's and No. of grains /spike

Results in Figure 5A illustrated that there were not significant variations on No. of spikelet's/spike ($p > 0.05$). No of spikelet's/spike and No. of grains/spike reached the highest values (21.03 and 55.81, respectively) applying Nan-N at 500 mg/L followed by the application of 250 mg/L during both successive years. Nevertheless, the lowest values (20.51 and 50.58, respectively) were documented from spraying of tap water as control. Further, the No. of grains/spike was significantly affected by high concentration of Nano-N applied compared to control during both years**.** The No. of grains/spike depends on No. of spikelet's. The production of organic matter/spike and spike weight are directly correlated with No. and weight of grains per spike (Protich *et al.*, 2012). Regarding No. of spikelet's, the data provided in Figure 5A presents non-significant variations due to the SA treatment. Higher concentration (200 mg/L) resulted in the highest No. of spikelet's (21.11). No. of spikelet is the most essential and effective variable that could affect the grain yield of the wheat (Leilah and Alkhateeb, 2005)**.**

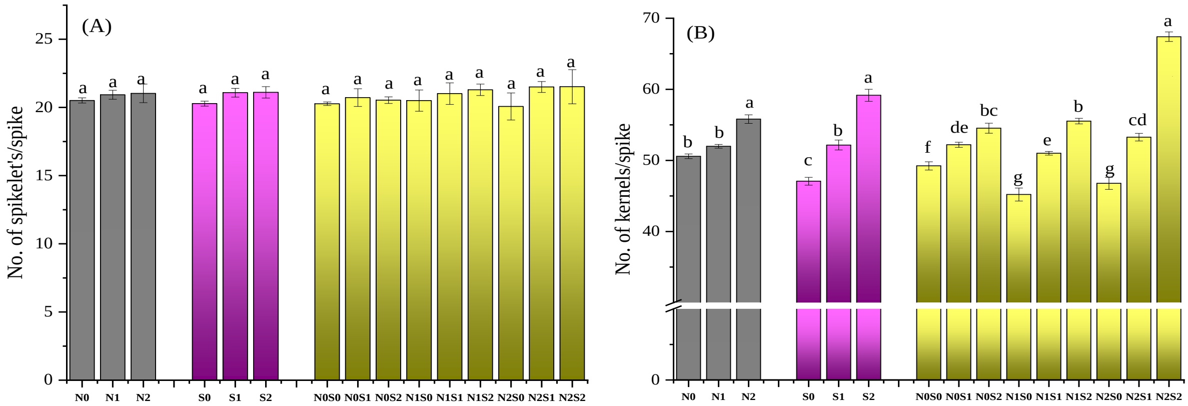

Figure 5. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the No. of spikelet's/spike (A) and No. of grains/spike (B) of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

Most importantly, it was noticed that, application of SA under varied concentrations (as listed in Figure 5B) significantly increased No. of grains/spike of wheat plants in the two seasons, reaching the highest value at 200 mg/L (59.16). However, the minimal value of No. of grains/spike was documented at zero SA (47.07). Further, the variations among the mean values of No. of grains/spike were considerably affected by the synergetic application of Nano-

N fertilizer and SA at varied concentrations (Figure 5B). The use of Nano-N at 500 mg/L and SA at 200 mg/L recorded the highest No. of grains/spike (67.40), whilst the lowest value (45.20) was realized after spraying of Nano-N at 250 mg/L and non-SA (0 mg/L).

5. Spike weight

The statistical outcomes indicated that the Nano-N treatment displayed non-significant effect on spike weight. The heaviest spikes (5.48 g) were recorded from Nano-N treatment at 500 mg/L.Whereas, the slightest spikes (5.21 g) were noticed for control group (Figure 6). Furthermore, the outcomes showed that there was a direct/positive effect of SA on spike weight of wheat. The highest value of spike weight (5.539 g) was observed at 100 mg/L across SA treatments, whereas the untreated plants (without SA) had the minimal spike wight (4.923 g). Such results were in good line with the findings of El-Nasharty *et al.* (2019) who noted that SA (at 100 mg/L) achieved the highest increase in spike weight. The observed enhancement may be due to its effect on total fertile blooms which resulted in increment of No. of grains per spike and thereafter increased spike weight. Additionally, the combined Nano-N and SA treatments exhibited no significant variation between the mean values of spike weight of wheat (Figure 6).

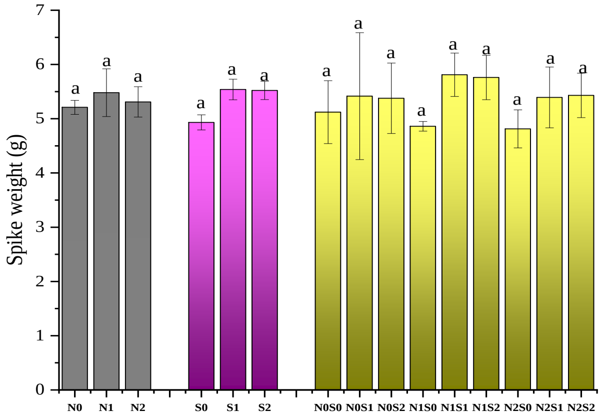

Figure 6. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the spike weight of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

6. Weight of 1000-grain

The results displayed in Figure 7 show that the application of Nano-N fertilizer had a notable influence on weight of 1000-grain of wheat. Highest weight of 1000-grain was noticed under the utilization of Nano-N at 250mg/L followed by 500 mg/L. Likened to untreated plants, Nano-N at 250 and 500 mg/L remarkably augmented the weight of 1000-grain by 22.55% and 9.91%, respectively ($p < 0.05$). In this view, comparable conclusion was reported by Al-Hasany (2019) who observed an inverse relationship between grain weight and No. of spikelet's. Additionally, SA treatments resulted in significant increases in 1000-grain weight over untreated plants and there was remarkable variation among treatments. The 1000-grain weight was increased significantly from 47.07 g in the untreated group to 59.16 g at 200 mg/L SA. Such results imply that SA has a controlling role in physiological process of fertilization, inducing a significant enhancement in grain weight through flowering (Kareem et al., 2017). Most remarkably, foliar spraying of Nano-N and SA resulted in a statistically significant improvement in weight of 1000-grain, and the maximal value (73.08 g) was noticed following the synergetic effect of 250 mg/L Nano-N and 200 mg/L SA. Untreated plants (Nano-N_0 x SA_0) possessed the least weight of 1000-grain (46.29 g) (Figure 7).

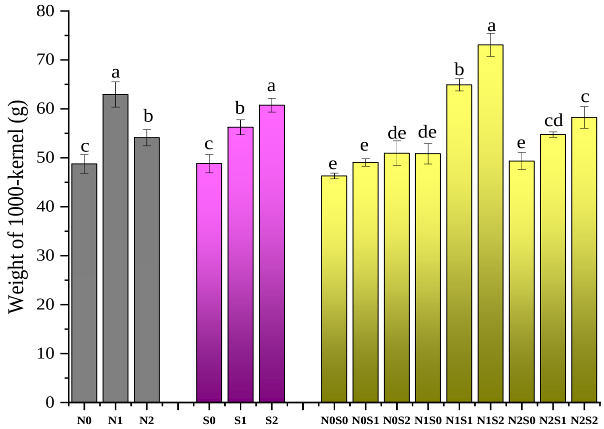

Figure 7. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the weight of 1000-grain of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

7. Grain, straw, and biological yield

Different concentrations of Nano-N fertilizer presented significant influence on straw, grain, and biological yield of wheat plants ($p < 0.05$) (Figures 8A-C). Maximum grain, straw, and biological yield were documented under the application of Nano-N at 500 mg/L (5612, 6938, and 12550 kg/ha, respectively) followed by other treatments (250 and 0 mg/ L, respectively). Further, the use of Nano-N at 250 and 500 mg/L dramatically improved grain (by 27.30 and 39.20%), straw (by 14.03 and 21.16%), and biological yield (by 19.67 and 29.44%) over untreated plants. These outcomes were in accordance with what has formerly been indicated (Ansar *et al.*, 2010). Such findings were attributed to the improvement in No. of spikes/m^2 and grains/spike (Malaker and Mian, 2009), as well as the enhancement in spike weight, plant height, No. of spikelet's, and No. of tillers/m^2, leading to increasing grain, straw, and biological yield. Additionally, nano-particles stimulated an enhancement in nutrient use efficacy and photosynthesis, resulting in increased grain yield (Morsy et al., 2018). The increase in straw, grain, and biological yield was in conformity with the findings of plant height, spike weight, No. of spikelet's, No. of tillers/m^2, weight of 1000-grain, spike length and No. of grains/spike in the current study. On the other hand, results exhibited that the foliar utilization of SA had similar effect on straw, grain, and biological yield of wheat plants as that observed after the use of Nano-N on the mentioned parameters. The maximal grain, straw, and biological yield were observed after applying of SA at 200 mg/L, whereas control treatment resulted in the minimal yields. Furthermore, SA at 100 and 200 mg/L substantially increased grain (by 15.05 and 30.05%), straw (by 27.67 and 28.07%), and biological yield (by 22.69 and 28.94%) reference to untreated plants. Similarly, El-Nasharty *et al.* [19] noticed that the maximal grain yield was found by spraying the plants with SA at 200 mg/L. This increase might be due to the augmented nutrient uptake, nitrate reduction, assimilation, and photosynthesis, as well as enhanced flow assimilates translocation and cytoplasmic streaming and improved cell integrity, thereby increasing yield (Amin *et al.*, 2008). This improvement also might be attributable to the fact that the application of SA improved the activity of various physiological and biochemical processes e.g., photosynthesis and activation of rubisco enzyme, flowering, and plant growth/development (Ashraf *et al.*, 2013; Hayat *et al.*, 2010). Such increase in straw, grain, and biological yield was mainly ascribed to the increased number of spikes/m^2 and weight of 1000-grain (Ibrahim *et al.*, 2014).

Furthermore, the synergetic application of Nano-N and SA showed significant effect on straw, grain, and biological yield of wheat plants ($p < 0.05$) (Figures 8A-C). For instance, plants sprayed with Nano-N and SA at 500 mg/L x 200 mg/L showed significantly higher grain yield (6648 kg/ha) reference to the interaction of non-sprayed Nano-N and without SA (2743 kg/ha). These observations were consistent with the outcomes of No. of grains/spike and weight of 1000-grain. Moreover, significant increase in straw and biological yield was found due to the interaction between Nano-N and SA at 500 mg/L x 250 mg/L over control or other treatments. This increase was possibly linked to largest plant height, No. tillers/ m^2, spike length, No. of spikelet's /spike, and grain yield.

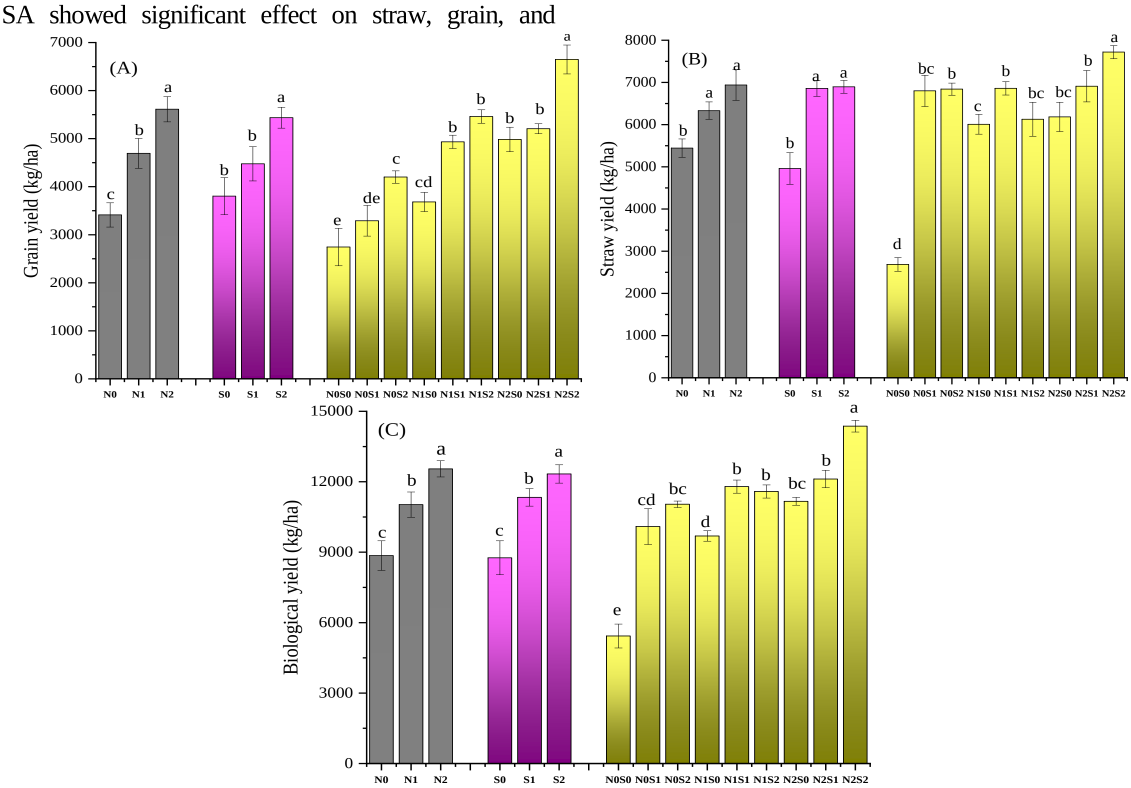

Figure 8. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the grain (A), straw (B), and biological (C) yield of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

8. Harvest index (HI)

HI can be denoted as the capability of plant to allocate photosynthetic material to produce economic yield. Results (Figure 9) illustrated that harvest index reached its highest values (44.72 %) subsequent to the utilization of Nano-N fertilizer at high concentration (500 mg/L). In contrast, the lowest value (38.53%) was documented after spraying of plants with tap water alone as control. Comparable results were also reported by Mijwel (2015). This observation was mainly linked to the increase in grain yield following the use of Nano-N, contributing to the notable increase in harvest index. Similarly, it can be observed that the influence of SA was not significant on HI. The highest HI value was recorded following spraying of wheat plants with SA at 200 mg/L. However, spraying of plants with tap water alone increased the HI over the application of SA at 100 mg/L, which reached 43.39%. The combined treatments of Nano-N and SA displayed significant variations on HI of wheat (Figure 9). The highest HI (50.52 %) was noticed subsequent to the utilization of N_0 and SA_0 (without Nano-N and SA). However, the lowest HI (32%) was recorded from Nano-N_0 and the plants sprayed with SA at 100 mg/L. The higher the HI, the superior the physiological capacity of the crops for converting dry matter to grain yield. These results are in harmony with those obtained by Kedir *et al.* (2023).

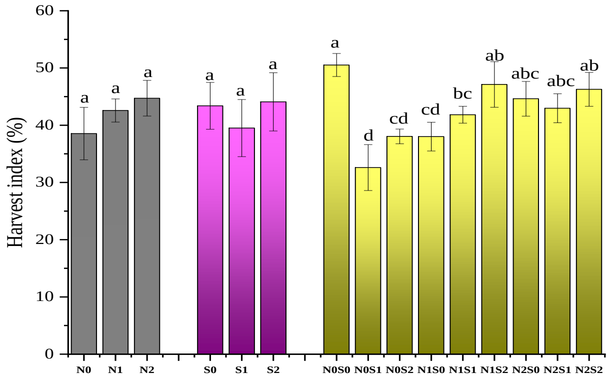

Figure 9. Effect of Nano-N fertilizer (N_0, N_1, and N_2), salicylic acid (S_0, S_1, and S_2), and their interactions on the harvest index of wheat. The means in same group (N, S, and NS) with same letter(s) are not significantly different at $p < 0.05$.

9. Correlational analysis

PCA was systematically applied on the results to improve the comprehension of the visual differences amongst experimental factors (i.e., Nano-N and SA) and their influences on the yield characteristics of wheat (Figure 10A). In such investigation, the overall variability (76.90%) determined from PC1 and PC2 was sufficient to clarify the similarity and/or variations between the two principal components. The Nano-N fertilizer and salicylic acid treatments were divided into four clusters. The first group (representing N_1SA_2 and N_2SA_2) is located on positive side of PC1 and PC2. This group was categorized by harvest index, No. of tillers, spike length, grain yield, No. of grains, weight of 1000-grain, and No. of spikelet's. Such observation indicated that the synergetic Nano-N fertilizer and salicylic acid treatments (at N_1SA_2 and N_2SA_2) had remarkable impacts on the said parameters. Additionally, N_1SA_1 and N_2SA_1 are positioned on the lower right-hand quadrant (positive and negative side of PC2 and PC1, respectively) with the spike weight, plant height, biological yield, and straw yield, illustrating that the results of the mentioned parameters were strongly correlated with the combined Nano-N fertilizer and salicylic acid treatments (at N_1SA_1 and N_2SA_1). Conversely, the remaining combined treatments (N_0SA_0, N_2SA_0, N_1SA_0, N_0SA_2, and N_0SA_1) showed no substantial interrelation with the dependent variables (i.e., measured parameters). Deducing from this is that, the Nano-N fertilizer and salicylic acid treatments under varying concentrations had diverse impacts on the yield attributes of wheat.

Moreover, to further elucidate the interrelationships between yield characteristics of wheat following targeted treatments (i.e., Nano-N fertilizer and SA), correlational analysis was used (Figure 10B). The red/ blue circles respectively denote positive/ negative correlation, whilst the darker colour represents stronger interrelation amongst the corresponding parameters. The analysis revealed that grain yield had positive/ direct correlation with No. of tillers (*r*= 0.75), plant height (*r*= 0.77), No. of spikelets (*r*= 0.70), spike length (*r*= 0.85), and No. of grains (*r*= 0.69). Furthermore, the increase of No. of tillers, plant height, No. of spikelet's, and spike length strongly contributed to the enhancement of biological yield by 69, 86, 71, and 78%, respectively. This demonstrated that the changes in yield components (No. of tillers, plant height, No. of spikelet's, and spike length) upon Nano-N fertilizer and salicylic acid treatments may have affected the grain and biological yield of wheat and vice versa. Comparable results have formerly been reported (El-Ganayni and Mahmoud, 2008). Correlational outcomes also displayed that there were weak negative interrelations between harvest index and plant height, straw yield, and biological yield. Most remarkably, the increase in No. of spikelet's was strongly accountable for 80, 72, 64, and 69% of the enhancement of spike length, No. of grains, weight of 1000-grain, and spike weight, respectively, showing good evidence of the correlation between No. of spikelet's and the said parameters. Such outcomes were in well accordance with what was previously indicated (Ibrahim et al. 2017; Okuyama et al., 2004).

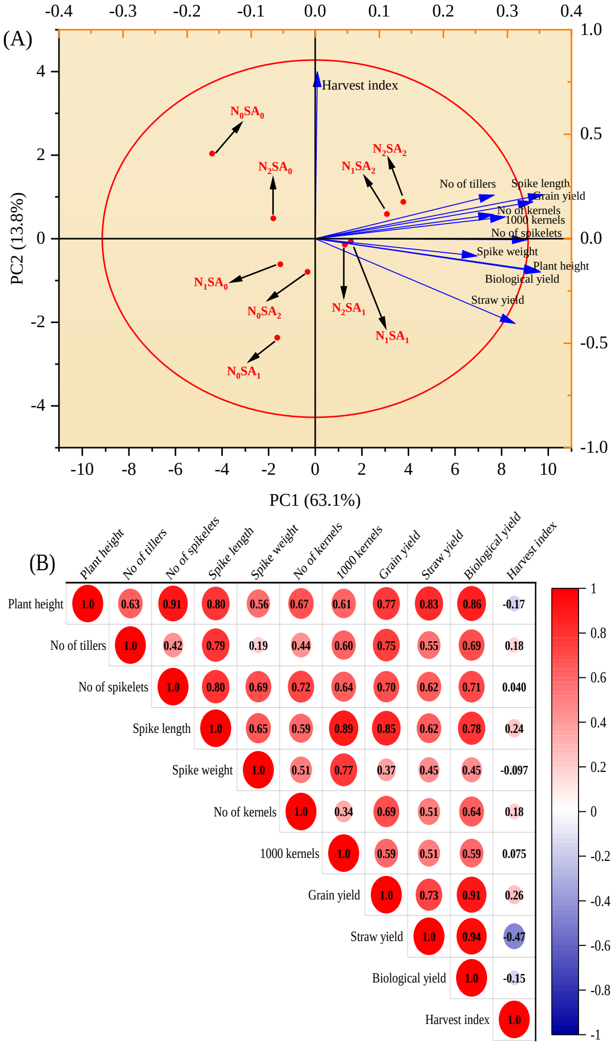

Figure 10. PCA (A) and Pearson's correlation (B) of yield characteristics of wheat treated with Nano-N fertilizer and salicylic acid.

CONCLUSION

The impact of two agronomical strategies (i.e., foliar spraying with Nano-N fertilizer and SA) on yield characteristics of wheat was investigated. The observations in the present work proved that high concentration of Nano-N and SA (500 and 200 mg/L, respectively) was beneficial on the yield attributes of wheat in comparison with the remaining treatments. Generally, using Nano-N fertilizer and SA treatments could be a hopeful practice for improving wheat production, but extensive research is required on diverse crops.

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تأثير الأسمدة النانومترية ومنظمات النمو على محصول القمح ومكوناته

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الملخص

تهدف التجربة إلى دراسة تأثير الرش الورقي بالسماد النانوي النيتروجيني (500،250،0 مجم/لتر) وحمض الساليسيليك (0 200،100 مجم/لتر) على إنتاجية القمح. نفذت التجارب فى تصميم القطع المنشقة فى ثلاثة مكررات. أجريت خلال الموسمين الشتويين 2022/2021 و2023/2022. أوضحت النتائج أن النانونيتروجين كان له تأثير ملحوظ في تحسين عدد الأشطاء/م^2، عدد الحبوب/السنبلة، محصول الحبوب، القش، والمحصول البيولوجي للقمح مقارنة بالكنترول ، ويمكن ملاحظة ذلك تحت التركيز العالي (500 مجم/لتر). لوحظ تأثير معنوى للرش بالسلسيليك اسيد على صفات إنتاجية القمح عند 200 مجم لتر. التفاعل بين النانونيتروجين عند 500 ملجم/لتر وحمض السلسيليك عند 200 ملجم/لتر أدى إلى زيادة كبيرة في محصول القش والحبوب والمحصول البيولوجي (7719، 6648، و14367 كجم/هكتار، على التوالي) مقارنة بالكنترول. أظهر التحليل الارتباطي أن محصول الحبوب لها علاقة موجبة/مباشرة مع عدد الاشطاء/م^2 (r= 0.75)، عدد ابراج السنبله (r= 0.70)، طول السنبلة (r= 0.85)، وعدد الحبوب فى السنبله (r = 0.69)، في حين أن زيادة ارتفاع النبات ساهمت بقوة في تعزيز المحصول البيولوجي بنسبة 86٪. وبالتالي، فإن النتائج الحالية توفر معلومات للمزارعين حول امكانية التطبيق العملي الأمثل لـلنانونيتروجين وحمض السلسيلك (500 x 200 مجم/لتر) لتعظيم إنتاج القمح.

الكلمات الدالة:- القمح- الأسمدة النانومترية - حمض السلسليك - المحصول البيولوجي- دليل الحصاد - محصول القش.