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Influence of NPK-quantum dots on germination and seedling growth observations of two wheat cultivars

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Abstract: The current study aimed to synthesize nitrogen, phosphorus, and potassium co-doped quantum dots (NPK-QDs); and to evaluate their influence on germination and seedling growth of wheat. Glucose, ammonia, and potassium phosphate were used to synthesize NPK-QDs using microwave. Visual observation and spectral analysis of the reaction mixture, along with transmission electron microscopy and elemental analysis, confirmed the formation of NPK-QDs. Seed priming of two wheat cultivars (Sakha 95 and Masr 3) in different concentrations of NPK-QDs (0, 25, 50, 100, and 200 mg/l) had marked effect on germination and seedling growth. These dots enhanced final germination percentage and mean daily germination by reducing mean germination time, germination final time, maximum germination time, and germination duration time. Consequently, germination index, germination rate index, peak value, germination value, speed of germination, and germination coefficient were all increased by NPK-QDs. In addition, NPK-QDs increased seedling vigor (indicated by seedling length and biomass) as well as seedling water retention. In most cases, NPK-QDs at 50 and 100 mg/l had the best effect. Thus, NPK-QDs at these concentrations can be recommended as priming agent to enhance wheat germination and early seedling growth.

keywords: wheat, germination, quantum dots, nitrogen, phosphorus, potasium

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most essential cereal crops; and its importance is derived from its great nutritional value. Therefore, wheat is the first choice for about one-third of the world population [1]. In this context, wheat is a potent source of energy owing to its content of carbohydrates, proteins, minerals, vitamins, and fibers [2]. However, continuous increase in global population necessitates the need for suitable strategies to feed the growing demand. By 2050, it is expected that population growth will exceed one billion [3]. In this regard, seed priming has long been practiced as an effective method to enhance crop productivity [4].

Productivity of essential crops is closely related to plant performance at juvenile stages; namely seed germination and seedling growth. Germination rate plays a crucial role in the plant life cycle from seedling establishment till vegetative growth and ultimate yield [5]. So, several studies were conducted to improve wheat germination in a trial to achieve the maximum yield [6]. In this regard, nanopriming has recently emerged as an effective strategy for sustainable seed treatment [7]. Different types of nanomaterials were used in this aspect; the most common of which are inorganic ones [8]. However, the use of carbon-based organic nanomaterials in this area is less explored.

Quantum dots (QDs) are zero-dimensional carbonaceous nanoparticles with unique features like good water solubility, high biocompatibility, and low toxicity [9]. Using QDs in agricultural field is an exciting topic where QDs can optimize plant growth leading to enhanced crop yield and improved food security. Seed priming with QDs was found to boost germination and early seedling growth of pea [10]. Also, QDs could accelerate germination and seedling growth of chickpeas, barley, mung beans, and wheat [11].

For QDs, doping with heteroatoms is effective in modifying physicochemical characteristics of these dots, thereby expanding their potential applications [12]. Doping QDs with different elements is common; but the choice of the dopant elements when used in agriculture is the main concern. Of particular importance, nano-formulations of nitrogen (N), phosphorus (P), and potassium (K) have been shown to enhance wheat growth [13]. Thus, our hypothesis is that seed priming in N, P, and K co-doped QDs (NPK-QDs) might improve germination and seedling growth of wheat; and such effect would vary with wheat cultivar and NPK-QDs concentration. To assess that, various germination parameters and seedling vigor indices had to be determined.

2. Materials and Methods

2.1. Synthesis and Characterization of NPK-QDs

A preliminary experiment was conducted to select the chemical precursors to synthesize NPK-QDs using a simple, low-cost, and eco-friendly technique. In 100 ml distilled water, a reaction mixture of 10 g glucose, 5 ml ammonia, and 5 g potassium phosphate was dissolved. The mixture was incubated in microwave at 900 W for 3 minutes followed by stirring. The solution was then centrifuged at 10,000 rpm and the supernatant was dried.

For characterization, the mixture was photographed under visible light and ultraviolet (UV) radiation at zero time and after reaction in microwave. Also, the mixture was analyzed using UV-visible spectrophotometer at 200-600 nm. The obtained NPK-QDs were further examined using transmission electron microscopy (TEM) and energy-dispersed X-ray analysis (EDX).

2.2. Seed priming in NPK-QDs

Two bread wheat cultivars (Sakha 95 and Masr 3) were obtained from Research and Training Center, Sakha, Egypt. The grains were sterilized by 0.01 M $HgCl_2$ followed by washing with sterile water. Grains of each cultivar were then primed in 0, 25, 50, 100, and 200 mg/l NPK-QDs for 16 hours. Priming was done in dark with continuous shaking at 180 rpm to enhance aeration. Primed grains were afterward germinated in sterilized plastic boxes at 25°C and received equal amounts of water through spraying. Throughout and after 7 days, germination parameters and seedling vigor indices were determined.

2.3. Germination parameters and seedling vigor indices

Various germination parameters and seedling vigor indices were determined as described in Table 1.

2.4. Statistical analysis

Two replicas were taken for germination parameters and four replicas for seedling vigor indices. Using CoHort/CoStat software, mean values and standard deviations were calculated. Also, an analysis of variance (ANOVA) test was performed with two designs; one-way completely randomized (1WCR) and two-way completely randomized (2WCR) design, both with the least significant difference as the means test at significance level of 0.05. In 1WCR ANOVA, all treatments were considered as a single factor. However, wheat cultivar was considered as a factor separated from NPK-QDs concentration as the second factor in 2WCR ANOVA.

3. Results and Discussion

As shown in Figure 1, the reaction mixture changed from transparent to yellow after incubating for 3 minutes in microwave. Thereafter, the mixture was tested under UV, where it emitted fluorescent blue light after incubation in microwave. The change in the optical properties is the first sign indicating the formation of QDs; and this was confirmed by an absorption peak at 280 nm using UV-visible spectroscopy (Figure 2). Interestingly, the obtained QDs had almost spherical shape with a nano-size less than 10 nm as revealed by TEM (Figure 3). Similar characteristics of QDs were previously recorded [25]. Moreover, EDX analysis confirmed the doping of N, P, and K into the QDs obtained herein according to their weight ratios (Figure 4).

Table 1: Germination parameters and seedling vigor indices determined in the current study; where *n* is the number of germinated seeds, *G* is the germination percentage, *d* is the day number, and *i* = 1, 2, 3and 7.

Parameter/ index	Symbol	Unit	Formula for calculation	Reference
Final germination percentage	FGP	%	FGP = final number of germinated seeds in a lot × 100	[14]
Germination final time	GFT	day	GFT = last day of germination	[15]
Maximum germination time	MGT	day	MGT = day of the highest germination	[15]
Germination duration time	GDT	day	GDT = MGT – first day of germination	[16]
Mean daily germination	MDG	%	MDG = FGP / MGT	[17]
Germination index	GI	-	$GI = \Sigma (n_i \times d_i)$	[18]
Germination rate index	GRI	%/day	$GRI = \Sigma (G_i / d_i)$	[19]
Peak value	PV	-	PV = the highest number of germinated seed / GFT	[20]
Germination value	GV	-	GV = PV × MDG	[20]
Germination speed	GS	seed/day	$GS = \Sigma (n_i / d_i)$	[21]
Germination coefficient	GC	%	$GC = 100 \times [N / \Sigma (n_i \times d_i)]$	[16]
Shoot length	SL	cm	Directly scored	-
Root length	RL	cm	Directly scored	-
Whole seedling length	WSL	cm	Directly scored	-
Seedling fresh mass	SFM	mg	Directly scored	-
Seedling dry mass	SDM	mg	Directly scored	-
Seedling turgid mass	STM	mg	Scored after water imbibition for 4 hours	-
Seedling length vigor index	SLVI	-	SLVI = FGP × WSL / 100	[22]
Seedling mass vigor index	SMVI	-	SMVI = FGP × SDM / 100	[22]
Relative water content	RWC	%	RWC = (SFM – SDM) / (STM – SDM) ×100	[23]
Water saturation deficit	WSD	%	WSD = 100 – RWC	[23]
Water retention	WR	-	WR = STM / SDM	[24]
Water uptake capacity	WUC	-	WUC = (STM – SFM) / SDM	[24]

In the current study, microwave-catalyzed hydrothermal reaction was followed as a simple, economic, and ecofriendly approach. In microwave, heat could be dispersed homogenously through the reaction mixture resulting in the formation of QDs within a short time [26]. The formed QDs were simultaneously doped with the most important elements for plants; N, P, and K, using safe precursors (glucose, ammonia, and potassium phosphate). Excess ammonia left after complete reaction could be evaporated by stirring.

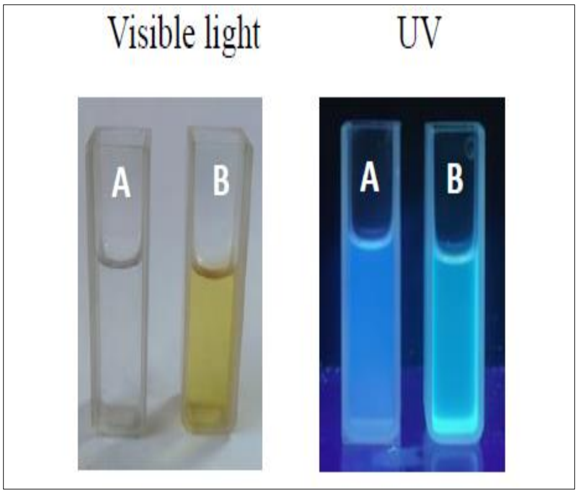

Figure 1. Color change of the reaction mixture (A) at zero time and (B) after 3 minutes in microwave to form NPK-QDs

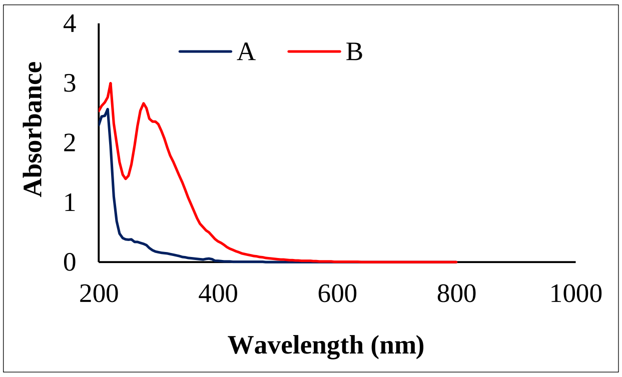

Figure 2. Spectral analysis of the reaction mixture (A) at zero time and (B) after 3 minutes in microwave to form NPK-QDs

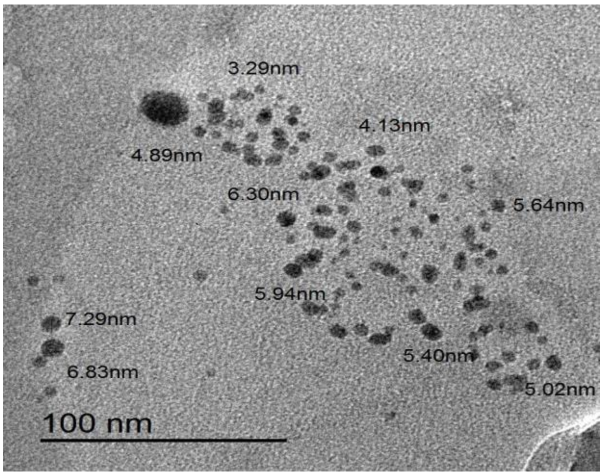

Figure 3. Transmission electron microscopy (TEM) of NPK-QDs

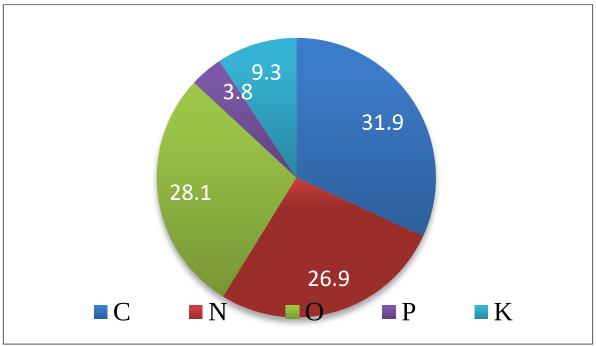

Figure 4. Energy dispersive X-ray (EDX) analysis of NPK-QDs

As shown in Table 2, seed priming in NPK-QDs could enhance germination parameters of the two wheat cultivars as indicated by higher final germination percentage (FGP) and mean daily germination (MDG) as well as lower germination final time (GFT), maximum germination time (MGT), and germination duration time (GDT).

For final germination percentage and mean daily germination of the two wheat cultivars, NPK-QDs at 50 mg/l caused the highest values in both traits. At the same time, NPK-QDs at 25 and 50 mg/l caused the lowest germination final time, maximum germination time, and germination duration time in the wheat cultivar Sakh 95. In Masr 3, the lowest values of these time traits were caused by NPK-QDs at 50 and 100 mg/l.

These responses indicated that NPK-QDs lowered the germination period and enhanced germinability in both cultivars. In a more or less similar pattern, Abinaya *et al.* [27] found that QDs could increase germination percentage of blackgram (*Vigna mungo*). The positive effect of NPK-QDs on germination parameters can be ascribed to the high content of C, O, N, P, and K of these nanodots. Such macronutrients are known to be essential for plants in their different growth stages.

Moreover, and as shown in Table 3, seed priming in NPK-QDs caused marked increase in germination index (GI), germination rate index (GRI), peak value (PV), germination value (GV), germination speed (GS), and germination coefficient (GC) of the two wheat cultivars. In most cases, NPK-QDs at 50 and 100 mg/l caused the maximum values of these germination parameters. Our findings are in accordance with those of Ahlawat *et al.* [28] who recorded that QDs could accelerate the speed of germination of black gramme (*Cicer arietinum*). Also, Chauhan *et al.* [11] reported that QDs could increase seed germination index of chickpeas, barley, mung beans, and wheat.

Regarding seedling vigor indices, results obtained herein indicated that seed priming in NPK-QDs caused significant increase in shoot, root, and the whole seedling length as well as seedling fresh and dry mass of the two wheat cultivars. Particularly, NPK-QDs at 50 and 100 mg/l caused the maximum values of these parameters. At the same time, Sakha 95 generally showed significant higher values of shoot, root, and the whole seedling length than Masr 3. However, there was no significant difference in seedling fresh and dry mass between the two cultivars (Table 4). In agreement with these results, Ren *et al.* [29] found that QDs improved shoot and root length and biomass of maize seedlings.

Table 2. Effect of seed priming in NPK-QDs on final germination percentage (FGP), germination final time (GFT), maximum germination time (MGT), germination duration time (GDT), and mean daily germination (MDG) of two wheat cultivars. Data listed represents mean values ± standard deviation with different superscript letters referring to significant variation at $p \leq 0.05$.

	NPK-QDs (mg/l)	FGP(%)	GFT(day)	MGT(day)	GDT(day)	MDG(%)
Sakha 95	0	$82.5^{c} \pm 2.5$	$6.5^{a} \pm 0.5$	$6.5^{a} \pm 0.5$	$5.5^{a} \pm 0.5$	$12.8^{d} \pm 1.4$
	25	$85.0^{bc} \pm 10.0$	$3.0^{cd} \pm 0.0$	$3.0^{cd} \pm 0.0$	$2.0^{cd} \pm 0.0$	$28.3^{bc} \pm 3.3$
	50	$95.0^{a} \pm 10.0$	$3.5^{bc} \pm 0.5$	$3.5^{bc} \pm 0.5$	$2.5^{bc} \pm 0.5$	$27.5^{bc} \pm 4.0$
	100	$95.0^{a} \pm 10.0$	$4.0^{b} \pm 0.0$	$4.0^{b} \pm 0.0$	$3.0^{b} \pm 0.0$	$23.8^{c} \pm 0.0$
	200	$95.0^{a} \pm 5.0$	$4.0^{b} \pm 0.0$	$4.0^{b} \pm 0.0$	$3.0^{b} \pm 0.0$	$23.8^{c} \pm 1.3$
Masr 3	0	$85.0^{bc} \pm 5.0$	$6.0^{a} \pm 1.0$	$6.0^{a} \pm 1.0$	$5.0^{a} \pm 1.0$	$14.3^{d} \pm 1.6$
	25	$85.0^{bc} \pm 10.0$	$3.0^{cd} \pm 0.0$	$3.0^{cd} \pm 0.0$	$2.0^{cd} \pm 0.0$	$28.3^{bc} \pm 0.0$
	50	$95.0^{a} \pm 10.0$	$2.5^{d} \pm 0.5$	$2.5^{d} \pm 0.5$	$1.5^{d} \pm 0.5$	$39.1^{a} \pm 8.0$
	100	$75.0^{d} \pm 10.0$	$2.5^{d} \pm 0.5$	$2.5^{d} \pm 0.5$	$1.5^{d} \pm 0.5$	$30.8^{b} \pm 6.3$
	200	$90.0^{ab} \pm 10.0$	$3.5^{bc} \pm 0.5$	$3.5^{bc} \pm 0.5$	$2.5^{bc} \pm 0.5$	$26.1^{bc} \pm 3.8$
Sakha 95		$90.5^{a} \pm 7.2$	$4.2^{a} \pm 1.3$	$4.2^{a} \pm 1.3$	$3.2^{a} \pm 1.3$	$23.2^{b} \pm 6.1$
Masr 3		$86.0^{b} \pm 7.1$	$3.5^{b} \pm 1.4$	$3.5^{b} \pm 1.4$	$2.5^{b} \pm 1.4$	$27.7^{a} \pm 9.3$
0 NPK-QDs		$83.8^{b} \pm 3.8$	$6.3^{a} \pm 0.8$	$6.3^{a} \pm 0.8$	$5.3^{a} \pm 0.8$	$13.6^{c} \pm 1.6$
25 NPK-QDs		$85.0^{b} \pm 6.3$	$3.0^{c} \pm 0.0$	$3.0^{c} \pm 0.0$	$2.0^{c} \pm 0.0$	$28.3^{b} \pm 2.1$
50 NPK-QDs		$95.0^{a} \pm 0.0$	$3.0^{c} \pm 0.7$	$3.0^{c} \pm 0.7$	$2.0^{c} \pm 0.7$	$33.3^{a} \pm 8.5$
100 NPK-QDs		$85.0^{b} \pm 11.0$	$3.3^{bc} \pm 0.9$	$3.3^{bc} \pm 0.9$	$2.3^{bc} \pm 0.9$	$27.3^{b} \pm 5.6$
200 NPK-QDs		$92.5^{a} \pm 4.2$	$3.8^{b} \pm 0.4$	$3.8^{b} \pm 0.4$	$2.8^{b} \pm 0.4$	$24.9^{b} \pm 2.8$

Table 3. Effect of seed priming in NPK-QDs on germination index (GI), germination rate index (GRI), peak value (PV), germination value (GV), germination speed (GS), and germination coefficient (GC) of two wheat cultivars. Data listed represents mean values ± standard deviation with different superscript letters referring to significant variation at $p \leq 0.05$.

	NPK-QDs (mg/l)	**GI**	**GRI(%/day)**	**PV**	**GV**	**GS(seed/day)**	**GC(%)**
Sakha 95	0	365^{f} ± 32	17324^{d} ± 532	2.6^{d} ± 0.3	32.9^{c} ± 7.0	12.3^{d} ± 1.2	49.0^{d} ± 5.8
	25	437^{cd} ± 43	19789^{c} ± 1843	5.7^{bc} ± 0.7	162.0^{b} ± 37.8	15.0^{c} ± 1.3	74.7^{ab} ± 4.3
	50	501^{ab} ± 5	22966^{a} ± 167	5.5^{bc} ± 0.8	154.6^{b} ± 44.0	17.6^{a} ± 0.1	79.3^{a} ± 3.3
	100	470^{bc} ± 18	21299^{b} ± 916	4.8^{c} ± 0.0	112.8^{bc} ± 0.0	16.2^{bc} ± 0.8	66.2^{bc} ± 6.9
	200	451^{c} ± 4	20132^{bc} ± 620	4.8^{c} ± 0.3	113.0^{bc} ± 11.9	15.1^{c} ± 0.8	60.9^{c} ± 8.3
Masr 3	0	379^{ef} ± 9	16864^{d} ± 246	2.9^{d} ± 0.3	41.7^{c} ± 9.1	12.7^{d} ± 0.1	50.7^{d} ± 4.5
	25	409de ± 13	17789^{d} ± 750	5.7^{bc} ± 0.0	160.6^{b} ± 0.0	13.0^{d} ± 0.7	63.3^{c} ± 4.7
	50	505^{a} ± 13	22882^{a} ± 750	7.9^{a} ± 1.6	317.5^{a} ± 126.2	17.3^{ab} ± 0.7	83.2^{a} ± 7.2
	100	386^{ef} ± 6	17196^{d} ± 250	6.3^{b} ± 1.3	197.9^{b} ± 78.6	12.8^{d} ± 0.2	75.2^{ab} ± 3.8
	200	453^{c} ± 12	20419^{bc} ± 667	5.3^{bc} ± 0.8	138.8^{b} ± 39.5	15.4^{c} ± 0.6	69.6^{bc} ± 5.4
Sakha 95		445^{a} ± 52	20302^{a} ± 2098	4.7^{b} ± 1.2	115.1^{b} ± 52.6	15.2^{a} ± 2.0	66.0^{a} ± 12.1
Masr 3		426^{b} ± 50	19030^{b} ± 2427	5.6^{a} ± 1.9	171.3^{a} ± 109.4	14.3^{b} ± 2.0	68.4^{a} ± 12.3
0 NPK-QDs		372^{d} ± 22	17094^{d} ± 448	2.72^{c} ± 0.3	37.3^{c} ± 8.7	12.5^{d} ± 0.8	49.9^{c} ± 4.7
25 NPK-QDs		423^{c} ± 32	18789^{c} ± 1668	5.67^{b} ± 0.4	161.3^{b} ± 23.9	14.0^{c} ± 1.4	69.0^{b} ± 7.4
50 NPK-QDs		503^{a} ± 9	22923^{a} ± 488	6.73^{a} ± 1.7	236.1^{a} ± 122.9	17.5^{a} ± 0.5	81.3^{a} ± 5.5
100 NPK-QDs		428^{c} ± 48	19247^{c} ± 2326	5.50^{b} ± 1.1	155.4^{b} ± 68.2	14.5^{bc} ± 1.9	70.7^{b} ± 7.0
200 NPK-QDs		452^{b} ± 8	20276^{b} ± 597	5.00^{b} ± 0.6	125.9^{b} ± 29.7	15.3^{b} ± 0.6	65.3^{b} ± 7.9

Table 4. Effect of seed priming in NPK-QDs on shoot length (SL), root length (RL), whole seedling length (WSL), shoot fresh mass (SFM), and shoot dry mass (SDM) of two wheat cultivars. Data listed represents mean values ± standard deviation with different superscript letters referring to significant variation at $p \leq 0.05$.

	NPK-QDs (mg/l)	**SL(cm)**	**RL(cm)**	**WSL(cm)**	**SFM(mg)**	**SDM(mg)**
Sakha 95	0	10.8^{fg} ± 0.9	12.6^{bc} ± 2.0	23.4^{de} ± 2.8	146^{d} ± 26	24^{bc} ± 4
	25	12.8^{def} ± 2.2	15.8^{ab} ± 1.8	28.6^{bc} ± 0.6	159^{d} ± 15	22^{bc} ± 4
	50	18.7^{a} ± 0.5	18.7^{a} ± 2.2	37.4^{a} ± 2.2	268^{a} ± 17	31^{a} ± 3
	100	15.5^{bc} ± 0.7	15.7^{ab} ± 4.0	31.3^{b} ± 4.6	194^{c} ± 10	24^{bc} ± 3
	200	11.2^{efg} ± 1.6	12.1^{bcd} ± 4.4	23.4^{de} ± 5.2	155^{d} ± 15	23^{bc} ± 4
Masr 3	0	10.5^{g} ± 0.9	8.2^{de} ± 1.7	18.7^{ef} ± 2.	158^{d} ± 8	20^{c} ± 3
	25	13.5^{cd} ± 1.0	11.2^{cde} ± 1.0	24.7^{cd} ± 1.9	215^{bc} ± 11	19^{c} ± 2
	50	16.0^{b} ± 1.0	14.4^{bc} ± 2.8	30.4^{b} ± 3.5	238^{b} ± 13	27^{ab} ± 7
	100	13.2^{de} ± 1.2	11.9^{bcde} ± 1.1	25.0^{cd} ± 0.1	189^{c} ± 6	26^{ab} ± 5
	200	8.0^{h} ± 1.7	7.8^{e} ± 1.3	15.8^{f} ± 0.5	142^{d} ± 28	25^{abc} ± 3
Sakha 95		13.8^{a} ± 3.3	15.0^{a} ± 3.6	28.8^{a} ± 6.2	184^{a} ± 49	25^{a} ± 4
Masr 3		12.2^{b} ± 3.0	10.7^{b} ± 2.9	22.9^{b} ± 5.6	189^{a} ± 39	24^{a} ± 5
0 NPK-QDs		10.6^{c} ±0.8	10.4^{c} ± 3.0	21.1^{c} ± 3.5	152^{c} ± 18	22^{b} ± 4
25 NPK-QDs		13.2^{b} ±1.6	13.5^{b} ± 2.8	26.7^{b} ± 2.5	187^{b} ± 33	21^{b} ± 3
50 NPK-QDs		17.4^{a} ± 1.7	16.6^{a} ± 3.2	33.9^{a} ± 4.7	253^{a} ± 21	29^{a} ± 5
100 NPK-QDs		14.4^{b} ± 1.5	13.8^{ab} ± 3.4	28.2^{b} ± 4.5	192^{b} ± 8	25^{ab} ± 4
200 NPK-QDs		9.6^{c} ± 2.3	10.0^{c} ± 3.8	19.6^{c} ± 5.3	148^{c} ± 21	24^{b} ± 3

Table 5. Effect of seed priming in NPK-QDs seedling length vigor index (SLVI), seedling mass vigor index (SMVI), relative water content (RWC), water saturation deficit (WSD), water retention (WR), and water uptake capacity (WUC) of two wheat cultivars. Data listed represents mean values ± standard deviation with different superscript letters referring to significant variation at $p \leq 0.05$.

	NPK-QDs (mg/l)	SLVI (%)	SMVI (%)	RWC (%)	WSD (%)	WR	WUC
Sakha 95	0	$1936^{def} \pm 273$	$2.0^{bcd} \pm 0.3$	$82.7^{a} \pm 6.7$	$17.3^{a} \pm 6.7$	$7.0^{cd} \pm 0.3$	$1.1^{a} \pm 0.5$
	25	$2435^{cd} \pm 332$	$1.9^{cd} \pm 0.2$	$84.6^{a} \pm 3.7$	$15.4^{a} \pm 3.7$	$8.3^{bcd} \pm 0.7$	$1.1^{a} \pm 0.3$
	50	$3556^{a} \pm 207$	$3.0^{a} \pm 0.3$	$85.8^{a} \pm 6.7$	$14.2^{a} \pm 6.7$	$9.9^{b} \pm 1.2$	$1.3^{a} \pm 0.8$
	100	$2970^{b} \pm 441$	$2.3^{bc} \pm 0.3$	$87.3^{a} \pm 3.2$	$12.7^{a} \pm 3.2$	$9.2^{bc} \pm 0.8$	$1.0^{a} \pm 0.3$
	200	$2212^{de} \pm 460$	$2.2^{bcd} \pm 0.5$	$84.1^{a} \pm 8.6$	$15.9^{a} \pm 8.6$	$7.9^{bcd} \pm 0.5$	$1.1^{a} \pm 0.6$
Masr 3	0	$1595^{fg} \pm 299$	$1.7^{d} \pm 0.3$	$87.6^{a} \pm 2.7$	$12.4^{a} \pm 2.7$	$9.2^{bc} \pm 1.2$	$1.0^{a} \pm 0.4$
	25	$2100^{de} \pm 162$	$1.6^{d} \pm 0.2$	$90.2^{a} \pm 2.3$	$9.8^{a} \pm 2.3$	$12.3^{a} \pm 1.1$	$1.1^{a} \pm 0.4$
	50	$2888^{bc} \pm 333$	$2.6^{ab} \pm 0.6$	$91.2^{a} \pm 3.8$	$8.8^{a} \pm 3.8$	$10.0^{b} \pm 3.1$	$0.8^{a} \pm 0.4$
	100	$1878^{efg} \pm 4$	$2.0^{cd} \pm 0.4$	$87.3^{a} \pm 4.9$	$12.7^{a} \pm 4.9$	$8.3^{bcd} \pm 1.6$	$1.0^{a} \pm 0.5$
	200	$1419^{g} \pm 42$	$2.3^{bc} \pm 0.3$	$83.4^{a} \pm 17.0$	$16.6^{a} \pm 17.0$	$6.6^{d} \pm 0.6$	$1.0^{a} \pm 1.1$
Sakha 95		$2622^{a} \pm 669$	$2.3^{a} \pm 0.5$	$84.9^{a} \pm 5.4$	$15.1^{a} \pm 5.4$	$8.5^{a} \pm 1.2$	$1.1^{a} \pm 0.5$
Masr 3		$1976^{b} \pm 560$	$2.0^{a} \pm 0.5$	$87.9^{a} \pm 7.5$	$12.1^{a} \pm 7.5$	$9.3^{a} \pm 2.5$	$1.0^{a} \pm 0.5$
0 NPK-QDs		$1766^{c} \pm 317$	$1.8^{bc} \pm 0.3$	$85.1^{a} \pm 5.3$	$14.9^{a} \pm 5.3$	$8.1^{bc} \pm 1.4$	$1.1^{a} \pm 0.4$
25 NPK-QDs		$2267^{b} \pm 297$	$1.8^{c} \pm 0.2$	$87.4^{a} \pm 4.1$	$12.6^{a} \pm 4.1$	$10.3^{a} \pm 2.3$	$1.1^{a} \pm 0.3$
50 NPK-QDs		$3222^{a} \pm 442$	$2.8^{a} \pm 0.5$	$88.5^{a} \pm 5.7$	$11.5^{a} \pm 5.7$	$9.9^{ab} \pm 2.1$	$1.1^{a} \pm 0.6$
100 NPK-QDs		$2424^{b} \pm 660$	$2.1^{bc} \pm 0.3$	$87.3^{a} \pm 3.7$	$12.7^{a} \pm 3.7$	$8.7^{b} \pm 1.2$	$1.0^{a} \pm 0.4$
200 NPK-QDs		$1816^{c} \pm 524$	$2.2^{b} \pm 0.4$	$83.8^{a} \pm 12.1$	$16.2^{a} \pm 12.1$	$7.2^{c} \pm 0.9$	$1.1^{a} \pm 0.8$

Results in Table 5 also revealed that seed priming in NPK-QDs increased seedling mass and length vigor indices. In addition, NPK-QDs increased relative water content (RWC) but decreased water saturation deficit (WSD) in both cultivars; but these effects were non-significant at $p \leq 0.05$. Also, NPK-QDs increased water retention (WR) of both cultivars; with 25 and 50 mg/l NPK-QDs showing the maximum effect. Regarding water uptake capacity (WUC), the effect of NPK-QDs was non-significant in both cultivars at $p \leq 0.05$. The increase recorded herein in RWC and WR can be ascribed to high oxygen content of NPK-QDs (as revealed by EDX analysis) that can facilitate water absorption. Similar assumption was proposed by Mickky [30] who reported that N-doped QDs could significantly increase water content of rice seedlings as compared to untreated seedlings.

Therefore, and based on the results obtained herein, NPK-QDs can be recommended as potent priming agents for wheat to enhance germination and early seedling stages. The most promising concentrations are 50 and 100 mg/l on the cultivars Sakha 95 and Masr 3. Further studies on vegetative and yield stages are vital to unravel the exact mechanism by which NPK-QDs can affect wheat growth and development.

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4. References

1 Saddiq MS, Iqbal S, Hafeez MB, Ibrahim AM, Raza A, Fatima EM, Baloch H, Jahanzaib, Woodrow P, Ciarmiello LF. (2021) Effect of salinity stress on physiological changes in winter and spring wheat. Agronomy,;**11(6)**:1193.

2 Naz T, Sharif MK, Shukat R, Israr B. (2025) Characterizing germination effects on nutrient and anti-nutrient profiles in cereal-based protein-enriched supplement. *Journal of Food Measurement and Characterization*.;1-3.

3 Abtew W. ,(2025) Climate Change and the Nile Basin. *In*: Nile Water Conflict and the Grand Ethiopian Renaissance Dam. Springer Geography. Springer, Cham.

4 Mickky BM. (2022) Seed priming as a strategy to improve wheat productivity under abiotic stress: global meta-analysis. *Journal of Plant Growth Regulation*,;**41(4)**:1397-1410.

5 Liu S, Wang W, Lu H, Shu Q, Zhang Y, Chen Q. (2022) New perspectives on

physiological, biochemical and bioactive components during germination of edible seeds: A review. Trends in Food Science and Technology,;**123**:187-197.

6 Faisal S, Muhammad S, Luqman M, Hasnain M, Rasool A, Awan MU, Khan ZI, Hussain I. (2023) Effects of priming on seed germination, physico-chemistry and yield of late sown wheat crop (*Triticum aestivum* L.). Polish *Journal of Environmental Studies,*;**32(2)**.

7 Shelar A, Singh AV, Chaure N, Jagtap P, Chaudhari P, Shinde M, Chaskar M, Patil R, Nile SH. (2024) Nanoprimers in sustainable seed treatment: molecular insights into abiotic-biotic stress tolerance mechanisms for enhancing germination and improved crop productivity. Science of The Total Environment.;175118.

8 Nile SH, Thiruvengadam M, Wang Y, Samynathan R, Shariati MA, Rebezov M, Nile A, Sun M, Venkidasamy B, Xiao J, Kai G. (2022) Nano-priming as emerging seed priming technology for sustainable agriculture-recent developments and future perspectives. *Journal of Nanobiotechnology*,;**20(1)**:254.

9 Hu Y, Neumann C, Scholtz L, Turchanin A, Resch-Genger U, Eigler S. Polarity, (2023) intramolecular charge transfer, and hydrogen bond co-mediated solvent effects on the optical properties of graphene quantum dots. Nano Research,;**16(1)**:45-52.

10 Liang L, Wong SC, Lisak G. (2023) Effects of plastic-derived carbon dots on germination and growth of pea (*Pisum sativum*) via seed nano-priming. Chemosphere,;**316**:137868.

11 Chauhan P, Kumari M, Chaudhary S, Chaudhary GR, Umar A, Baskoutas S. (2022) Seed germination studies on chickpeas, barley, mung beans and wheat with natural biomass and plastic waste derived C-dots. Science of The Total Environment,;837:155593.

12 Kou X, Jiang S, Park SJ, Meng LY. A (2020) review: Recent advances in preparations and applications of heteroatom-doped carbon quantum dots. Dalton Transactions,;**49(21)**:6915-2938.

13 Abdel-Aziz HM, Hasaneen MN, Omer AM. (2018) Foliar application of nano chitosan NPK fertilizer improves the yield of wheat plants grown on two different soils. Egyptian *Journal of Experimental Biology*,;**14(1)**:63-72.

14 Scott SJ, Jones RA, Williams W. (1984) Review of data analysis methods for seed germination. Crop Science,;**24(6)**:1192-1199.

15 Al-Mudaris MA. (1998) Notes on various parameters recording the speed of seed germination. Der Tropenlandwirt-*Journal of Agriculture in the Tropics and Subtropics*,;**99(2)**:147-154.

16 Hefny YA, Mohamed NE, Abdelraoof AO, Sleem HA. (2020) Germination parameters of some bread wheat genotypes under drought stress conditions. SVU-International *Journal of Agricultural Sciences*,;**2(2)**:226-241.

17 Fetouh MI, Hassan FA. (2014) Seed germination criteria and seedling characteristics of Magnolia grandiflora L. trees after cold stratification treatments. *International Journal of Current Microbiology and Applied Sciences*,;**3(3)**:235-241.

18 Chen P, Jiang L, Yang W, Wang L, Wen Z. (2022) Seed germination response and tolerance to different abiotic stresses of four Salsola species growing in an arid environment. Frontiers in Plant Science,;**13**:892667.

19 Baskin CC, Baskin JM. (1998) Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination. Academic Press;.

20 Gairola KC, Nautiyal AR, Dwivedi AK. (2011) Effect of temperatures and germination media on seed germination of Jatropha curcas Linn. Advances in Bioresearch,;**2(2)**:66-71.

21 Zewdie T, Welka K. (2015) Effect of micropyle orientation on germination of Millettia ferruginea and Delonix regia. Ecological Processes,;**4**:1-7.

22 Kharb RP, Lather BP, Deswal DP. (1994) Prediction of field emergence through heritability and genetic advance of vigour parameters. Seed Science and Technology,;**22**, 461–466.

23 Barrs HD, Weatherley PE. (1962) A re-examination of the relative turgidity technique for estimating water deficits in leaves. Australian *Journal of Biological Sciences*,;**15**:413-428.
24 Sangakkara UR, Hartwig UA, Nösberger J. (1996) Response of root branching and shoot water potentials of French beans (Phaseolus vulgaris L.) to soil moisture and fertilizer potassium. *Journal of Agronomy and Crop Science*,;**177(3)**:165-173.
25 Jeevika A, Alagarsamy G, Celestina JJ. (2022) Biogenic synthesis of carbon quantum dots from garlic peel bio-waste for use as a fluorescent probe for sensing of quercetin. Luminescence,;**37(11)**:1991-2001.
26 Shi Y, Xu H, Yuan T, Meng T, Wu H, Chang J, Wang H, Song X, Li Y, Li X, Zhang Y. (2022) Carbon dots: An innovative luminescent nanomaterial: Photovoltaics: Special Issue Dedicated to Professor Yongfang Li. Aggregate,;**3(3)**:e108.
27 Abinaya K, Raja K, Raja K, Sathya Moorthy P, Senthil A, Chandrakumar K. (2024) Impact of green carbon dot nanoparticles on seedling emergence, crop growth and seed yield in blackgram (Vigna mungo L. Hepper). Scientific Reports,;**14(1)**:23783.
28 Ahlawat A, Rana PS, Solanki PR. A (2024) simple and highly efficient approach towards the degradation of methylene blue and study the impact of degraded water on seed germination of *Cicer* arietinum. Nano Express,;**5(1)**:015027.
29 Ren Y, Li X, Cheng B, Yue L, Cao X, Wang C, Wang Z. (2024) Carbon dot-embedded hydrogels promote maize germination and growth under drought stress. Environmental Science: Nano,;**11(5)**:2239-2248.
30 Mickky BM. (2025) N-doped quantum dots promote rice germination and enhance its drought tolerance at seedling stage. *Journal of Soil Science and Plant Nutrition*, **25**:528-542.