Egypt. J. Soil Sci. **Vol. 63**, No. 3, pp: 367-380 (2023)

Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Effect of Tuber Soaking Types and Fertilization Rates on Growth and Productivity of Potato

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To address the current challenge of rising fertilizer costs and limited expansion of cultivated areas in Egypt, a field experiment was conducted for two successive seasons (2021 and 2022) to evaluate the effect of different tuber soaking techniques before planting and various rates of NPK recommended doses on potato growth and quality attributes. A split plot design with complete randomized blocks, consisting of 15 treatments; the soaking types included no soaking, soaking in normal water, and soaking in magnetized water, while the fertilization rates comprised 100% NPK of the recommended dose, fulvic acid+ 75% NPK from the recommended dose, fulvic acid+ 50% NPK of the recommended dose, biochar+ 75% NPK from the recommended dose, and biochar+ 50% NPK from the recommended dose. The results indicated that soaking tubers in magnetized water before planting yielded the highest values in terms of vegetative growth parameters, chlorophyll contents, ion percentage, potato yield, and quality. Furthermore, plants fertilized with 100% NPK of the recommended dose exhibited the maximum vegetative growth and yield. Likewise, the treatment involving fulvic acid+ 75% NPK showed the maximum values in terms of chlorophyll contents, nutrients percentage, and tuber quality. Based on these findings, it is recommended to soak tubers in magnetized water before planting and fertilize the plants with fulvic acid+ 75% NPK of the recommended dose. This approach can help reduce production costs by 25% while still achieving high potato yield and quality.

Keywords: Magnetized water, soaking types, fulvic acid, biochar.

1. Introduction

Potato *(Solanum tuberosum* L.) belongs to the family Solanaceae and is one of the most important vegetables (Sahair et al., 2018). It is considered a significant source of the national income in Egypt, providing low-cost carbohydrates and a variety of vitamins and nutrients that are crucial in human diet. Potatoes have great value as an export commodity in the European and Arab markets and serve as a major source of national income.

Soaking potato tubers before planting decreases the sprouting stage of buds, leading to improved growth and also decrease the risks high temperatures by the end of the growing season, which affect potato storage (Kandil et al., 2012; Abd El-Hady et al., 2016; Abd El-Hady and Shehata, 2019; Hamaiel et al., 2021). Magnetized water has been proved to enhance plant growth and development both qualitatively and quantitatively, as well as improve seed and tuber germination. Therefore, it is considered one of the most promising methods to

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Received: 01/06/2023; Accepted: 26/06/2023
DOI: 10.21608/EJSS.2023.214870.1603

increase agricultural production in an eco-friendly manner (Silva and Dobranzki, 2014).

There is a close relationship between mineral fertilization levels of NPK and potato productivity (Abdelhalem, 2023). In this regard, Eleiwa (2012) and El-Metwaly (2020) demonstrated that increasing NPK levels enhances potato growth and productivity. However, many farmers face difficulties in applying sufficient amounts of chemical fertilizer due to their rising costs and concerns about environmental pollution. Hence, it has become crucial to employ alternative fertilizers to substitute partially or totally chemical fertilizers. In this context, El-Metwaly (2020) and Youseef et al. (2017) indicated that organic sources such as biochar and fulvic acid hold promises as additives to chemical fertilizers. The use of biochar and fulvic acid in agriculture offers several advantages, including rapid nutrient supply, enhanced soil fertility, improved plant productivity, cost reduction, and decreased environmental pollution (El-Metwaly (2020). Biochar application for example enhances microbial activity in the soil especially beneficial soil biota, increases water retention capacity (Bassouny and Abbas, 2019), and enhances the resilience of soil aggregates while decreasing erosivity (Jeffery et al., 2011; Sun and Lu, 2014). Fulvic acid is another important organic matter constituent that plays a crucial role in various environmental and soil ecological processes (Aminifard, 2012; Farid et al., 2023). It increases soil buffering capacity, as well as aiding in the release and retention of metal ions and organic compounds in the soil (Farid et al., 2018; Fukami et al., 2018).

Therefore, the aim of this study is to investigate the effect of soaking the tubers with different types of water (magnetized water, normal water), various levels of NPK, and the addition of biochar or fulvic acid on potato growth, tuber yield, and quality. The goal is to reduce costs and environmental pollution while also accelerating plant growth.

2. Materials and Methods

A field experiment was conducted at a private farm near Aga city, El-Dakahlia governorate, for two successive seasons: 2021 and 2022 to investigate the effects of different types of tuber soaking (without soaking, soaking in tap water, soaking in magnetized water) and various fertilization rates (100% NPK from the recommended dose, fulvic acid + 75% NPK, fulvic acid + 50% NPK, biochar + 75% NPK, biochar + 50% NPK) on the vegetative growth parameters, chlorophyll content, nutrient content, potato yield, and quality. The experimental design was a split-plot design with three replicates, where soaking types were assigned to the main plots and fertilization rates to the subplots.

Each divided potato tuber piece (Solanum tuberosum L., cv. Cara) weighed 10 g. Pieces were divided into three groups: the first one was soaked in normal water, the second group in magnetized water for 3 hours, while the third group was left without soaking. Magnetized water was prepared via passing water into an electromagnetic field generator (1 inch diameter) obtained from Delta Water Company, with magnetic induction ranged between 100 and 150 mT. The tuber pieces were planted on ridges at intervals of 25 cm on January 3rd and 6th during the 2021 and 2022 seasons, respectively. The plot area was 14.7 m², with three ridges, each measuring 0.7 m in width and 7 m in length. A random soil sample (0-30 cm) from the experiment was collected prior to the field study to determine its physical and chemical characteristics according to Sparks et al. (2020) (see Table 1).

N fertilizer was applied at a rate of 350 kg N/ha as the recommended dose, divided into three equal parts. The first part, consisting of ammonium sulfate (20.6% N), was added after planting and before the first irrigation. The second and third parts, consisting of ammonium nitrate (33.5% N), were added with the second and third irrigations, respectively. P fertilizer was applied at a rate of 75 kg P/ha as the recommended dose of calcium superphosphate. K fertilizer was applied at a rate of 185 kg K/ha as the recommended dose of potassium sulfate (48% K_2O), divided into two equal parts and added with the second and third irrigations. All recommendations of the Egyptian Ministry of Agriculture were followed.

Fulvic acid was applied at a rate of 25 kg/ha it was obtained from the Canza group company potassium fulvate 80%, while biochar was applied at a rate of 12 m³/ha and was produced from the residues of guava trees stover without oxygen for 30 minutes at 400–500 °C, according to Wang and Wang (2019), it contain 652 g kg^{-1} organic carbon, 1.1% total nitrogen, 73, 14 and 243 mg kg^{-1} available nutrients of N, P, and K, respectively. Fulvic acid and biochar were added in the middle of the rows and covered with soil before planting.

The following data were recorded:

- After 75 days of planting, six plants were randomly selected (2 from each ridge) to measure the following vegetative growth parameters: number of leaves per plant, number of branches per plant, fresh weight (g/plant), plant height (cm), and dry matter (%).

- Chlorophyll content (mg/g Fw): Chlorophyll a, b, and a+b were measured as described by Lichtenthaler and Wellburn (1985).
- Nutrient percentages in leaves and tubers:
- N, P, and K % were measured in dry leaf and tuber samples after being wet digested with sulphuric and perchloric acid mixture, a sample of 0.2g of crude, dried-up powder was quantitively put into a 50 ml measuring flask with distilled water and retained for analysis according to AOAC (2012).
- Yield and its components:
- Plant yield (kg) and marketable and total tuber yield (Mg/ha) were recorded at the harvesting stage, 145 days after planting.
- Tuber quality:
- Total sugar (%) was determined using the method described by Malik and Srivastava (1979).
- Reducing and non-reducing sugar % was measured according to the method described by Somogy (1952).
- Total Soluble Solids (TSS) % was estimated using a refractometer based on AOAC (2012).
- Starch % was measured as described by Somogy (1952).
- Vitamin C (mg/100 g Fw) was estimated using the 2,6-dichlorophenol indophenol method described in AOAC (2012).
- Protein %: N in tuber % was multiplied by 6.25 to calculate it.

Statistical analysis:

The data were subjected to analysis of variance (ANOVA) using the methodology described by Gomez and Gomez (1984). The Duncan Multiple Range Test was employed to compare the means of different treatments (Duncan, 1955).

Table 1. Physical and chemical properties of experimental soil (average two seasons):

Mechanical analysis (%)				Texture class	OM (%)	Total $CaCO_3$ (g kg^{-1})	SP (%)	EC $dS.m^{-1}$ 1:5	pH (1:2.5)	Available nutrient (mg kg^{-1} soil)		
Coarse Sand	Fine Sand	Silt	Clay							N	P	K
4.47	29.27	37	29.26	Clay loamy	1.03	4.22	55.75	1.01	8.04	41.1	5.4	169.75

SP: Saturation percentage OM: Organic matter

3. Results

Vegetative growth parameters

Table 2 reveals that all vegetative growth parameters, including the number of leaves, number of branches, fresh weight, plant height, and dry matter, were significantly affected by the different soaking types. Soaking the tubers before planting in magnetized water recorded the highest increases in all the abovementioned growth parameters, followed by soaking in normal water. On the other hand, tubers planted without soaking exhibited the lowest values.

Regarding the impact of fertilization rates, the results presented in the same table indicate that vegetative growth parameters were generally enhanced by the application of 100% NPK, except for dry matter yield. However, the combination between fulvic acid and 75% NPK resulted in the highest dry matter content. In the first season, there were no significant variations observed between 100% NPK and Fulvic+75%NPK in terms of the number of leaves, fresh weight, and plant height. The number of branches showed no significant differences between 100% NPK and Fulvic+75%NPK in the two seasons.

Regarding the interaction effect between soaking types and fertilization rates, the results demonstrate that soaking tubers in magnetized water before planting, combined with the application of Fulvic+75%NPK, led to the highest increases in vegetative growth parameters. No significant differences were found between 100% NPK and Fulvic+75%NPK in terms of the number of leaves and number of branches in both seasons of study. Additionally, there was no significant variations in fresh weight in the second season.

Table 2. Vegetative growth parameters of potato as affected by soaking types and fertilization rates during 2021 and 2022 seasons.

Treatments	Characters	No. of leaves/plant		No. of branches /plant		Fresh weight (g)		Plant height (cm)		Dry matter %	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
A- Soaking types:											
Without		26.20 c	25.53 c	5.47 c	5.80 c	181.80 c	202.20 c	41.27 c	45.00 c	18.12 c	19.17 b
Normal water		27.60 b	26.87 b	6.07 b	6.40 b	193.27 b	220.33 b	43.80 b	48.07 b	18.31 b	19.22 b
Magnetized water		29.00 a	28.40 a	6.60 a	7.00 a	209.47a	237.13 a	46.53 a	51.20 a	18.53 a	20.33 a
B- Fertilization:											
100 % NPK		33.11 a	31.89 a	7.89 a	8.11 a	250.67a	288.44 a	51.44 a	58.67 a	18.31 c	19.20 c
Fulvic + 75% NPK		32.89 a	31.11 b	7.78 a	8.22 a	250.33 a	282.22 b	51.33 a	57.78 b	19.53 a	21.05 a
Fulvic + 50% NPK		28.22 b	26.67 c	6.00 b	6.56 b	199.78 b	217.56 c	45.00 b	48.11 c	18.93 b	20.10 b
Biochar + 75% NPK		24.11 c	23.89 d	4.89 c	5.11 c	151.00 c	172.22 d	38.89 c	40.78 d	17.72 d	19.18 c
Biochar + 50% NPK		19.67 d	21.11 e	3.67 d	4.00 d	122.44 d	139.00 e	32.67 d	35.11 e	17.11 e	18.34 d
A × B - Interaction:											
Without	100 % NPK	31.67 de	29.67 cd	7.33 bc	7.33 cd	240.67c	263.67 d	48.33 e	54.33 e	18.12 i	19.40cd
	Fulvic + 75% NPK	31.00 e	28.67 de	6.67 cd	7.33 cd	229.67 d	257.00 e	47.67 e	52.33 f	19.31 c	20.55abc
	Fulvic + 50% NPK	26.67 h	25.67 gh	5.67def	6.00 ef	182.67 g	200.67 h	43.00 h	46.00 i	18.72 f	19.51cd
	Biochar + 75% NPK	22.67 j	23.00 j	4.33gh	4.67 hi	136.33 j	161.33 k	37.00 k	38.67 l	17.51 l	18.83d
	Biochar + 50% NPK	19.00 l	20.67 k	3.33 h	3.67 j	119.67 k	128.33 n	30.33 n	33.67 o	16.93n	17.57e
Normal water	100 % NPK	33.33 bc	32.33 b	8.00b	8.33 b	246.67 c	294.00 b	52.00 c	59.67 c	18. 32h	17.52e
	Fulvic + 75% NPK	32.67 cd	30.33 c	7.67 b	8.00 bc	248.67 c	280.00 c	50.33 d	57.00 d	19.52 b	21.06ab
	Fulvic + 50% NPK	28.33 g	26.67 fg	6.00def	6.67 de	200.33 f	216.00 g	45.33 g	48.00 h	18.93 e	19.87bcd
	Biochar + 75% NPK	24.33 i	24.00 hi	5.00 fg	5.00 gh	148.33 i	172.33 j	38.67 j	40.67 k	17.71 k	19.17d
	Biochar + 50% NPK	19.33 l	21.00 k	3.67 h	4.00 ij	122.33 k	139.33 m	32.67 m	35.00 n	17.05 n	18.48de
Magnetized water	100 % NPK	34.33 ab	33.67 a	8.33 ab	8.67 ab	264.67 b	307.67 a	54.00 b	62.00 b	18.49 g	20.67abc
	Fulvic + 75% NPK	35.00 a	34.33 a	9.00 a	9.33 a	272.67 a	309.67 a	56.00 a	64.00 a	19.74 a	21.55a
	Fulvic + 50% NPK	29.67 f	27.67 ef	6.33de	7.00 d	216.33 e	236.00 f	46.67 f	50.33 g	19.12 d	20.93ab
	Biochar + 75% NPK	25.33 i	24.67 ij	5.33 ef	5.67 fg	168.33 h	183.00 i	41.00 i	43.00 j	17 .94 j	19.54cd
	Biochar + 50% NPK	20.67 k	21.67 k	4.00 h	4.33 hij	125.33 k	149.33 l	35.00 l	36.67m	17.35m	18.96d

Various letters in the same column that show a significant variation according to the Duncan Multiple Test ($P < 0.05$)

Chlorophyll contents

Figure 1 demonstrate that the different soaking types had a significant influence on the levels of chlorophyll a, chlorophyll b, and chlorophyll a+b. Soaking the tubers in magnetized water significantly raised in chlorophyll a+b content by 1.47% and 3.37% compared to soaking in normal water and no soaking, respectively, during the first season. Similarly, in the second season, soaking tubers in magnetized water led to an increase of 1.50% and 3.84% in chlorophyll a+b compared to soaking in normal water and no soaking, respectively.

Furthermore, the application of Fulvic+75%NPK fertilizer significantly enhanced the levels of chlorophyll contents compared to all other fertilization rates as shown in Figure 2.

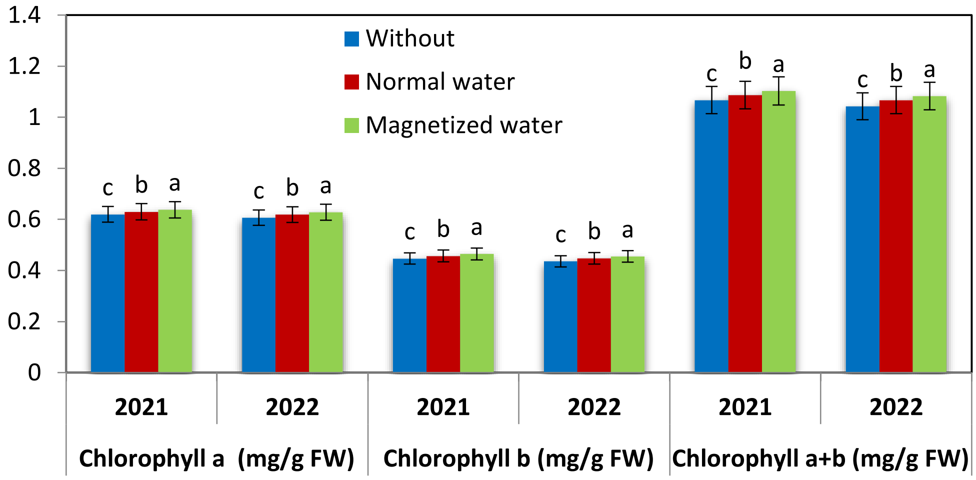

Fig. 1. Impact of soaking types of tubers pre sowing on chlorophyll contents of potato plants. Various letters show significant differences between treatments according to Duncan test ($p \leq 0.05$).

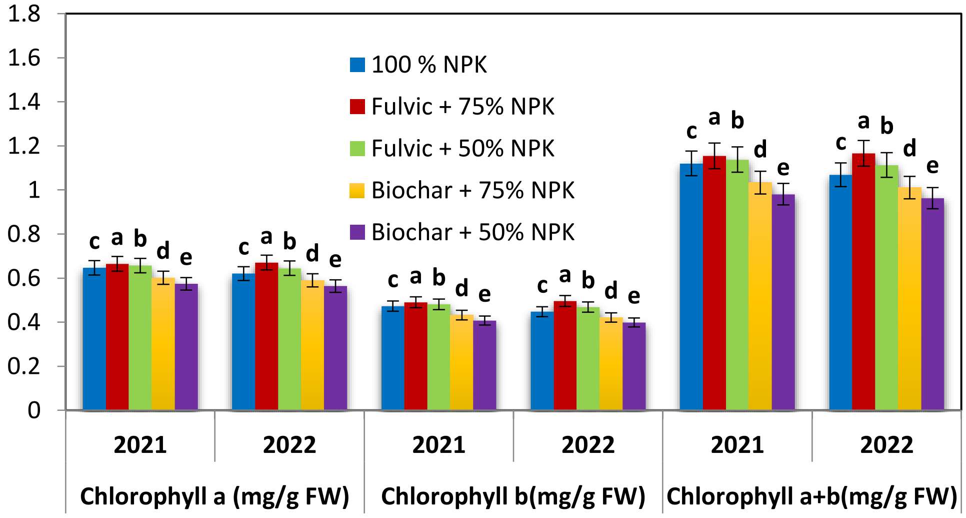

Fig. 2. Impact of fertilization rates on chlorophyll contents of potato plants. Various letters show significant differences between treatments according to Duncan test ($p \leq 0.05$).

The results presented in the Figures 3 and 4 indicate that soaking the tubers in magnetized water and fertilizing with 100% NPK resulted in the highest chlorophyll contents during the first season. On the other hand, soaking the tubers in magnetized water and fertilizing with Fulvic+75%NPK led to the maximum chlorophyll contents in the second season. There were no significant differences observed between soaking the tubers in magnetized water and fertilizing with Fulvic+75%NPK, and soaking the tubers in normal water and fertilizing with Fulvic+75%NPK in terms of chlorophyll a and chlorophyll a+b during the second season (Figure 4).

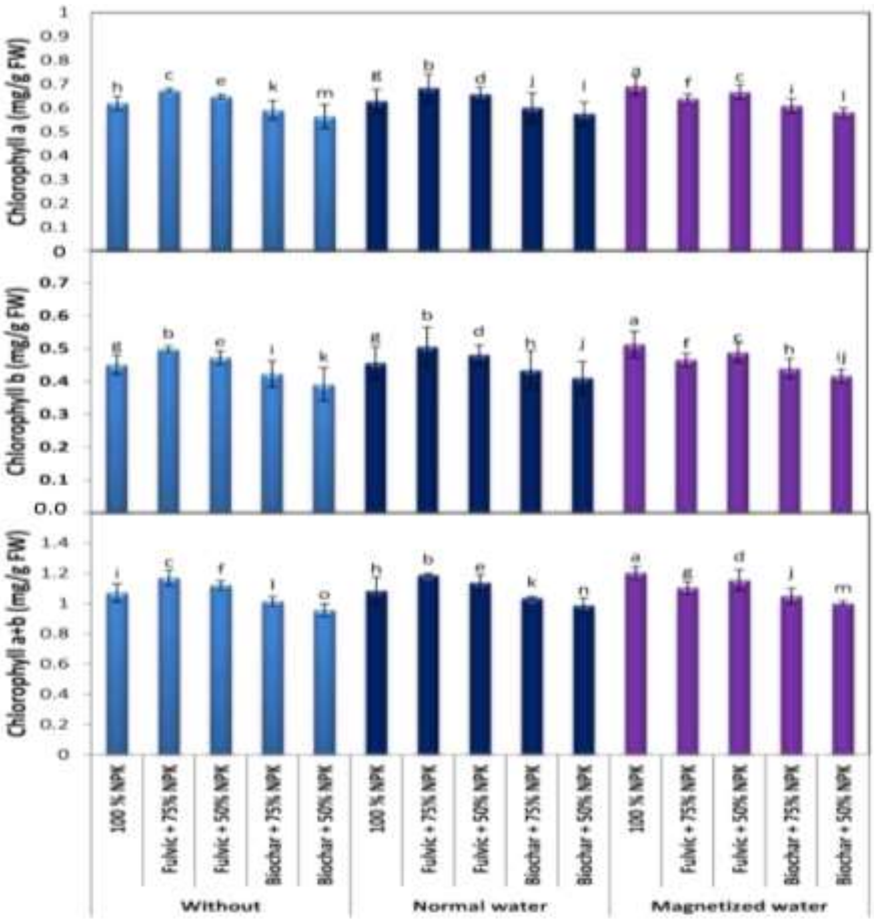

Fig. 3. Impact of soaking types and fertilization rates on chlorophyll contents of potato plants in the first season. Various letters show significant differences between treatments according to Duncan test ($p \leq 0.05$).

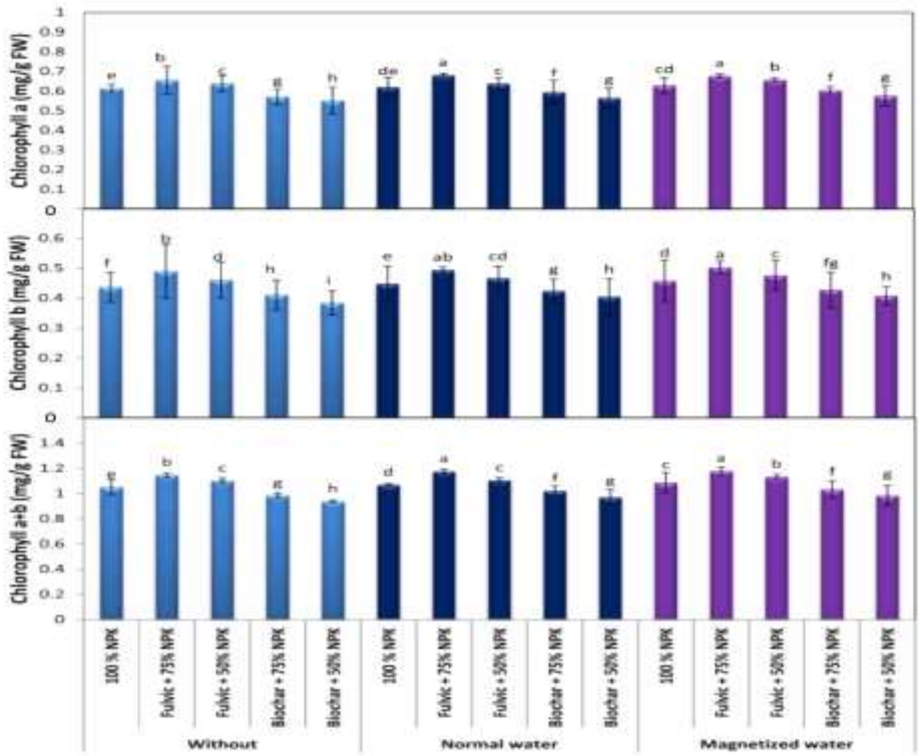

Fig. 4. Impact of soaking types and fertilization rates on chlorophyll contents of potato plants in the second season. Various letters show significant differences between treatments according to Duncan test ($p \leq 0.05$).

Nutrients percentage in leaves and tubers:

Results presented in Tables 3 and 4 demonstrate that soaking the tubers in magnetized water before planting had a significant positive impacts on increasing the nutrient contents in both leaves and tubers compared to the other soaking types (i.e., without soaking and soaking in normal water).

Table 3. Nutrients percentage of potato leaves as affected by soaking types and fertilization rates during 2021 and 2022 seasons.

Treatments \ Characters		N %		P %		K %	
		2021	2022	2021	2022	2021	2022
A- Soaking type:							
Without		2.31 c	2.52 c	0.237 c	0.253 c	2.59 c	2.72 c
Normal water		2.42 b	2.61 b	0.248 b	0.267 b	2.70 b	2.90 b
Magnetized water		2.51 a	2.78 a	0.258 a	0.279 a	2.82 a	3.09 a
B- Fertilization:							
100 % NPK		2.60 c	2.85 c	0.264 c	0.280 c	2.93 c	3.13 c
Fulvic + 75% NPK		2.81 a	3.04 a	0.286 a	0.308 a	3.15 a	3.36 a
Fulvic + 50% NPK		2.73 b	2.95 b	0.278 b	0.295 b	3.03 b	3.25 b
Biochar + 75% NPK		2.12 d	2.34 d	0.220 d	0.242 d	2.36 d	2.53 d
Biochar + 50% NPK		1.81 e	2.00 e	0.191 e	0.208 e	2.03 e	2.25 e
A × B - Interaction:							
Without	100 % NPK	2.29 i	2.50 g	0.228 g	0.243 ef	2.61 h	2.71 h
	Fulvic + 75% NPK	2.91 c	3.13 bc	0.297 b	0.312 ab	3.25 c	3.35 cd
	Fulvic + 50% NPK	2.64 f	2.86 e	0.270 d	0.284 cd	2.91 f	3.07 f
	Biochar + 75% NPK	2.04 l	2.25 hi	0.211 h	0.228 fg	2.23 k	2.36 j
	Biochar + 50% NPK	1.69 o	1.85 k	0.180 k	0.198 i	1.94 n	2.09 l
Normal water	100 % NPK	2.40 h	2.62 f	0.250 f	0.270 d	2.69 g	2.90 g
	Fulvic + 75% NPK	3.04 b	3.21 b	0.303 b	0.322 ab	3.37 b	3.57 b
	Fulvic + 50% NPK	2.71 e	2.95 d	0.277 d	0.294 c	3.04 e	3.25 de
	Biochar + 75% NPK	2.11 k	2.33 h	0.219 h	0.244 ef	2.36 j	2.54 i
	Biochar + 50% NPK	1.84 n	1.95 j	0.191 j	0.208 hi	2.03 m	2.23 k
Magnetized water	100 % NPK	3.11 a	3.42 a	0.314 a	0.327 a	3.48 a	3.78 a
	Fulvic + 75% NPK	2.49 g	2.79 e	0.259 e	0.289 c	2.84 f	3.15 ef
	Fulvic + 50% NPK	2.83 d	3.05 c	0.287 c	0.308 b	3.14 d	3.41 c
	Biochar + 75% NPK	2.21 j	2.46 g	0.230 g	0.254 e	2.49 i	2.68 h
	Biochar + 50% NPK	1.90 m	2.19 i	0.202 i	0.217 gh	2.14 l	2.44 j

Various letters in the same column that show a significant variation according to the Duncan Multiple Test ($P < 0.05$).

Table 4. Ion percentage of potato tubers as affected by soaking types and fertilization rates during 2021 and 2022 seasons.

Treatments \ Characters		N %		P %		K %	
		2021	2022	2021	2022	2021	2022
A- Soaking type:							
Without		1.91 c	1.85 c	0.209 c	0.221 c	2.23 c	2.06 c
Normal water		1.99 b	2.10 b	0.218 b	0.227 b	2.34 b	2.17 b
Magnetized water		2.08 a	2.20 a	0.229 a	0.248 a	2.43 a	2.31 a
B- Fertilization:							
100 % NPK		2.18 c	2.32 a	0.239 c	0.251 c	2.53 c	2.40 c
Fulvic + 75% NPK		2.35 a	2.37 a	0.257 a	0.272 a	2.78 a	2.59 a
Fulvic + 50% NPK		2.26 b	2.32 a	0.248 b	0.260 b	2.65 b	2.49 b
Biochar + 75% NPK		1.72 d	1.74 b	0.189 d	0.203 d	2.01 d	1.87 d
Biochar + 50% NPK		1.47 e	1.50 c	0.159 e	0.174 e	1.69 e	1.56 e
A × B - Interaction:							
Without	100 % NPK	1.92 i	1.94 e	0.212 i	0.223 f	2.22 h	2.06 f
	Fulvic + 75% NPK	2.44 c	2.35 c	0.266 c	0.279 bc	2.90 b	2.71 bc
	Fulvic + 50% NPK	2.17 f	2.13 d	0.240 f	0.249 d	2.54 e	2.36 e
	Biochar + 75% NPK	1.63 l	1.53 h	0.177 l	0.190 g	1.90 k	1.71 h
	Biochar + 50% NPK	1.40 o	1.29 i	0.149 o	0.163 h	1.58 n	1.47 i
Normal water	100 % NPK	2.00 h	2.33 c	0.221 h	0.232 e	2.33 g	2.23 e
	Fulvic + 75% NPK	2.53 b	2.49 b	0.276 b	0.283 b	2.99 a	2.78 b
	Fulvic + 50% NPK	2.26 e	2.33 c	0.248 e	0.256 d	2.66 d	2.46 d
	Biochar + 75% NPK	1.72 k	1.81 f	0.186 k	0.197 g	2.02 j	1.84 g
	Biochar + 50% NPK	1.46 n	1.54 h	0.158 n	0.167 h	1.70 m	1.53 i
Magnetized water	100 % NPK	2.60 a	2.67 a	0.285 a	0.297 a	3.04 a	2.91 a
	Fulvic + 75% NPK	2.08 g	2.27 c	0.230 g	0.255 d	2.44 f	2.26 e
	Fulvic + 50% NPK	2.35 d	2.51 b	0.256 d	0.274 c	2.76 c	2.64 c
	Biochar + 75% NPK	1.81 j	1.89 e	0.204 j	0.223 f	2.12 i	2.06 f
	Biochar + 50% NPK	1.55 m	1.68 g	0.169 m	0.191 g	1.79 l	1.67 h

Various letters in the same column that show a significant variation according to the Duncan Multiple Test ($P < 0.05$)

Specifically, soaking the tubers in magnetized water resulted in higher N, P, and K contents in both leaves and tubers compared to the other soaking treatments.

Also, fertilization with Fulvic+75%NPK resulted in the highest nutrient percentages in both leaves and tubers compared to the other fertilization rates. A point to note is that there were no significant differences observed between 100% NPK, Fulvic+75%NPK, and Fulvic+50%NPK in terms of the nitrogen (N%) content in tubers during the second season.

Furthermore, the interaction effect between soaking types and fertilization rates revealed that soaking the tubers in magnetized water before planting and fertilizing with 100% NPK led to the highest nutrient percentages in both leaves and tubers during both seasons. Following this, soaking the tubers in normal water before planting and fertilizing with Fulvic+75%NPK resulted in the next highest nutrient percentages.

Tuber yield and its components:

The results presented in Table 5 demonstrate that soaking of tubers had a significant impact on the yield of potatoes. The highest plant yield, marketable yield, and total yield were obtained when tubers were soaked in magnetized water. In the first season, soaking tubers in magnetized water increased the total yield by 5.05% and 10.36% compared to either soaking in normal water or without soaking, respectively. Similarly, in the second season, the total yield was enhanced by 7.22% and 9.02% compared to soaking in normal water and not soaking the tubers, respectively.

Additionally, the results in the same table reveal that all fertilization rates had a significant effect on the yield of potatoes. Increasing the NPK rates up to 100% of the recommended dose resulted in significant increases in plant yield, marketable yield, and total yield of potatoes. The highest yield was obtained from plants fertilized with 100% NPK, followed by Fulvic+75%NPK from the recommended dose.

The results presented in the same table clearly indicate that soaking the tubers in magnetized water before planting and fertilizing with Fulvic+75%NPK resulted in the highest plant yield, marketable yield, and total yield of potatoes, followed by soaking the tubers in magnetized water before planting and fertilizing with 100% NPK. There were no significant differences observed in the marketable yield between soaking the tubers in magnetized water before planting and fertilizing with 100% NPK treatment and soaking the tubers in magnetized water before planting and fertilizing with 1 Fulvic + 75% NPK treatment. These findings highlight the effectiveness of using magnetized water for tuber soaking in combination with Fulvic+75%NPK fertilization in maximizing the yield of potatoes, particularly in terms of marketable yield.

Table 5: Potato yield as affected by soaking types and fertilization rates during 2021 and 2022 seasons.

Treatments \ Characters		Plant yield (kg)		Marketable yield (Mg/ha)		Total yield (Mg/ha)	
		2021	2022	2021	2022	2021	2022
A- Soaking type:							
Without		0.660 c	0.690 c	35.42 c	39.43 c	37.73 c	37.46 c
Normal water		0.694 b	0.724 b	37.59 b	41.37 b	39.64 b	38.09 b
Magnetized water		0.721 a	0.757 a	39.11 a	43.27 a	41.64 a	40.84 a
B- Fertilization:							
100 % NPK		0.788 a	0.839 a	43.00 a	47.95 a	45.00 a	45.23 a
Fulvic + 75% NPK		0.776 b	0.829 b	42.15 b	47.38 a	44.32 b	44.95 b
Fulvic + 50% NPK		0.695 c	0.730 c	37.47 c	41.71 b	39.70 c	38.75 c
Biochar + 75% NPK		0.639 d	0.648 d	34.51 d	37.05 c	36.50 d	34.59 d
Biochar + 50% NPK		0.562 e	0.572 e	29.76 e	32.69 d	32.14 e	30.48 e
A × B - Interaction:							
Without	100 % NPK	0.751 e	0.798 e	40.86 d	43.75 bc	42.91e	45.62 e
	Fulvic + 75% NPK	0.727 f	0.776 f	39.72 e	43.05 c	41.54 f	44.34 f
	Fulvic + 50% NPK	0.679 i	0.705 i	36.65 g	37.84 e	38.80 i	40.27 i
	Biochar + 75% NPK	0.613 l	0.619 l	32.41 i	33.29 gh	35.03 l	35.37 l
	Biochar + 50% NPK	0.532 o	0.552 o	27.51 k	29.38 i	30.38 o	31.56 o
Normal water	100 % NPK	0.793 c	0.849 c	43.08 b	44.71 b	45.33 c	48.53 c
	Fulvic + 75% NPK	0.773 d	0.822 d	42.22 c	43.52 bc	44.15 d	46.97 d
	Fulvic + 50% NPK	0.695 h	0.731 h	37.64 f	37.98 e	39.73 h	41.79 h
	Biochar + 75% NPK	0.643 k	0.648 k	35.30 h	34.24 g	36.72 k	37.03 k
	Biochar + 50% NPK	0.565 n	0.569 n	29.70 j	29.98 i	32.27 n	32.51 n
Magnetized water	100 % NPK	0.818 b	0.870 b	45.06 a	47.22 a	46.76 b	49.70 b
	Fulvic + 75% NPK	0.827 a	0.890 a	44.51 a	48.27 a	47.26 a	50.84 a
	Fulvic + 50% NPK	0.710 g	0.754 g	38.11 f	40.43 d	40.57 g	43.07 g
	Biochar + 75% NPK	0.661 j	0.678 j	35.83 h	36.23 f	37.75 j	38.76 j
	Biochar + 50% NPK	0.591 m	0.595 m	32.06 i	32.08 h	33.77 m	33.98 m

Various letters in the same column that show a significant variation according to the Duncan Multiple Test ($P < 0.05$)

Tubers quality:

The results presented in Tables 6 and 7 provide clear evidence that soaking tubers in magnetized water before planting significantly improved the quality of potatoes. In both seasons, soaking tubers in magnetized water resulted in significantly higher contents of reducing sugars, non-reducing sugars, total sugars, TSS (Total Soluble Solids), starch, vitamin C, and protein compared to soaking in normal water and not soaking the tubers. The only exception was non-reducing sugars in the second season, where there were no significant differences between soaking tubers in magnetized water and soaking tubers in normal water.

Furthermore, the results in the same tables demonstrate that fertilization rates had a significant impact on potato quality. The highest quality potatoes were obtained from plants fertilized with Fulvic+75%NPK.

Table 6. Potato tubers reducing and non reducing contents of total sugars as affected by soaking types and fertilization rates during 2021 and 2022 seasons.

Characters / Treatments		Reducing sugar %		Non reducing sugar %		Total sugar %	
		2021	2022	2021	2022	2021	2022
A- Soaking type:							
Without		2.56 c	2.77 c	4.66 c	4.81 b	7.22 c	7.58 c
Normal water		2.65 b	2.83 b	4.72 b	4.91 a	7.37 b	7.73 b
Magnetized water		2.73 a	3.01 a	4.80 a	4.98 a	7.54 a	7.99 a
B- Fertilization:							
100 % NPK		2.66 c	2.87 c	4.72 c	4.90 c	7.38 c	7.77 c
Fulvic + 75% NPK		3.17 a	3.38 a	5.12 a	5.33 a	8.29 a	8.71 a
Fulvic + 50% NPK		2.91 b	3.12 b	4.92 b	5.06 b	7.83 b	8.17 b
Biochar + 75% NPK		2.39 d	2.63 d	4.53 d	4.71 d	6.91 d	7.34 d
Biochar + 50% NPK		2.12 e	2.35 e	4.34 e	4.51 e	6.47 e	6.86 e
A × B - Interaction:							
Without	100 % NPK	2.57 i	2.79 ef	4.65 gh	4.83 efg	7.22 h	7.62 ef
	Fulvic + 75% NPK	3.08 c	3.28 b	5.06 abc	5.25 b	8.13 c	8.53 b
	Fulvic + 50% NPK	2.82 f	2.96 d	4.85 def	4.96 de	7.67 f	7.92 d
	Biochar + 75% NPK	2.31 l	2.60 g	4.45 ij	4.63 gh	6.76 k	7.23 gh
	Biochar + 50% NPK	2.03 o	2.24 h	4.29 j	4.39 i	6.32 n	6.63 j
Normal water	100 % NPK	2.65 h	2.86 de	4.71 fg	4.92 def	7.37 g	7.78 de
	Fulvic + 75% NPK	3.17 b	3.31 b	5.11 ab	5.30 ab	8.28 b	8.61 b
	Fulvic + 50% NPK	2.92 e	3.09 c	4.91 cde	5.04 cd	7.84 e	8.13c
	Biochar + 75% NPK	2.39 k	2.55 g	4.53 hi	4.74 fgh	6.92 j	7.29 g
	Biochar + 50% NPK	2.12 n	2.32 h	4.35 j	4.56 h	6.46 m	6.88 i
Magnetized water	100 % NPK	2.74 g	2.96 d	4.81 ef	4.96 de	7.55 f	7.92 d
	Fulvic + 75% NPK	3.25 a	3.56 a	5.20 a	5.43 a	8.45 a	8.99 a
	Fulvic + 50% NPK	2.99 d	3.32 b	5.00 bcd	5.17 bc	7.98 d	8.49 b
	Biochar + 75% NPK	2.47 j	2.73 f	4.61 gh	4.76 efgh	7.08 i	7.49 f
	Biochar + 50% NPK	2.22 m	2.51 g	4.39 ij	4.58 h	6.62 l	7.08 h

Various letters in the same column that show a significant variation according to the Duncan Multiple Test ($P < 0.05$)

Regarding the interaction between soaking types and fertilization rates, the results in the same tables reveal that soaking tubers in magnetized water and fertilizing with Fulvic+75%NPK resulted in the highest values of reducing, non-reducing, total sugar contents, TSS, starch, and vitamin C in both seasons. On the other hand, soaking tubers in magnetized water and fertilizing with 100% NPK gave the highest protein percentage.

Table 7. TSS, starch, vitamin C and protein contents of potato tubers as affected by soaking types and fertilization rates during 2021 and 2022 seasons.

Treatments	Characters	Total Soluble Solids (TSS)%		Starch %		Vitamin C mg/100g		Protein %	
		2021	2022	2021	2022	2021	2022	2021	2022
A- Soaking type:									
Without		9.20 c	9.46 c	20.47 c	20.32 c	18.81 c	20.02 b	10.98 c	10.62 c
Normal water		9.28 b	9.67 b	20.72 b	21.35 b	18.96 b	20.01 b	11.48 b	12.07 b
Magnetized water		9.37 a	9.70 a	20.96 a	22.07 a	19.10 a	20.49 a	11.94 a	12.67 a
B- Fertilization:									
100 % NPK		9.29 c	9.72 c	20.77 c	21.53 c	18.96 c	20.14 c	12.51 c	13.31 a
Fulvic + 75% NPK		9.82 a	10.10 a	22.23 a	22.63 a	19.83 a	21.02 a	13.50 a	13.62 a
Fulvic + 50% NPK		9.55 b	9.85 b	21.51 b	21.94 b	19.40 b	20.61 b	12.98 b	13.36 a
Biochar + 75% NPK		9.02 d	9.39 d	19.91 d	20.44 d	18.51 d	19.79 d	9.88 d	10.01 b
Biochar + 50% NPK		8.74 e	8.99 e	19.17 e	19.69 e	18.09 e	19.32 e	8.45 e	8.65 c
A × B - Interaction:									
Without	100 % NPK	9.21 i	9.56 d	20.52 i	20.33 f	18.82 h	19.91 c	11.04 i	11.17 e
	Fulvic + 75% NPK	9.73 c	9.94 b	21.99 c	21.85 c	19.67 bc	20.77 b	14.03 c	13.49 c
	Fulvic + 50% NPK	9.48 f	9.73 c	21.27 f	21.14 e	19.24 ef	20.54 b	12.46 f	12.25 d
	Biochar + 75% NPK	8.92 l	9.19 e	19.65 l	19.45 h	18.36 jk	19.81 c	9.35 l	8.78 h
	Biochar + 50% NPK	8.67 o	8.90 f	18.92 o	18.81 i	17.95 l	19.07 e	8.03 o	7.42 i
Normal water	100 % NPK	9.27 h	9.73 c	20.75 h	21.72 c	18.96 gh	19.86 c	11.52 h	13.42 c
	Fulvic + 75% NPK	9.81 b	10.18 a	22.23 b	22.90 a	19.83 ab	20.84 b	14.53 b	14.34 b
	Fulvic + 50% NPK	9.55 e	9.8 b8	21.52 e	21.82 c	19.42 de	20.46 b	12.98 e	13.38 c
	Biochar + 75% NPK	9.02 k	9.46 d	19.93 k	20.49 f	18.53 ij	19.63 cd	9.89 k	10.39 f
	Biochar + 50% NPK	8.75 n	9.11 e	19.17 n	19.84 g	18.07 l	19.27 de	8.41 n	8.87 h
Magnetized water	100 % NPK	9.40 g	9.88 b	21.03 g	22.54 b	19.09 fg	20.64 b	14.97 a	15.35 a
	Fulvic + 75% NPK	9.91 a	10.18 a	22.47 a	23.14 a	19.98 a	21.47 a	11.94 g	13.03 c
	Fulvic + 50% NPK	9.63 d	9.9 b5	21.75 d	22.86 a	19.54 cd	20.82 b	13.49 d	14.45 b
	Biochar + 75% NPK	9.11 j	9.52 d	20.17 j	21.37 d	18.65 i	19.91 c	10.39 j	10.87 e
	Biochar + 50% NPK	8.80 m	8.97 f	19.41 m	20.42 f	18.25 k	19.62 cd	8.89 m	9.66 g

Various letters in the same column that show a significant variation according to the Duncan Multiple Test ($P < 0.05$)

Overall, these findings highlight the importance of both soaking tubers in magnetized water and selecting an appropriate fertilization strategy, particularly using Fulvic+75%NPK, to enhance the quality of potatoes.

Discussion

The results of this study provide compelling evidence that soaking tubers before planting, whether in magnetized water or normal water, significantly enhances potato growth, chlorophyll contents, ion percentage, tuber yield, and quality. These findings can be attributed to the favourable moisture conditions provided by soaking, which prevent tuber rotting and promote optimal sprouting and cell division processes. This, in turn, leads to increased potato growth (Table 2) and chlorophyll contents (Figure 1), ultimately boosting photosynthesis and energy transfer from leaves to tubers, resulting in higher yield (Table 5). These results align with previous studies conducted by Kandil et al. (2012), Abd El-Hady et al. (2016), Abd El-Hady and Shehata (2019), and Hamaiel et al. (2021) on potato cultivation.

Results obtained herein showed that soaking tuber before planting in magnetized water increased vegetative growth, chlorophyll contents, nutrients percentage in leaves and tubers in addition tuber yield and quality. This technique may stimulate early root growth, leading to a robust root system throughout the plant's life cycle. This, coupled with increased cell division and protein synthesis, promotes plant growth by enhancing the production of plant hormones such as IAA, GA_3, and cytokinins, which, in turn, positively impact plant yield (Swelam, 2018). Similarly, exposing true potato seeds to a magnetic field, as demonstrated by El-Gizawy et al. (2016), resulted in improved germination percentage, vegetative growth, and tuber quality. The magnetic field likely increases the presence of ions, free radicals, and electrical charges, making cell membranes more permeable and facilitate ion uptake, ultimately promoting plant growth.

Vegetative growth parameters and yield were generally enhanced by application of 100% NPK, while the application of Fulvic+75%NPK fertilizer significantly enhanced chlorophyll and nutrients contents within potato in leaves and tubers in addition to the improvements that was observed in tubers quality. This may be due to enhance nutrient uptake with application of NPK fertilizers. Also cell division, amino acid synthesis, and various metabolic processes, improved considerably leading to increased production of photoassimilates that are transported to different plant sinks (Abd El-Hady and Abd-Elhamied, 2018), thereby improved potato yield. Nitrogen, in particular, plays a vital role in protein synthesis, nucleic acid production, and protoplasm formation, which stimulate meristematic activity and the development of additional tissues and organs, thereby promoting plant growth (Marschner, 1995). Phosphorus is an essential nutrient for energy metabolism, and its hydrolysis reactions provide the high energy required for various chemical reactions that support plant growth. Phosphorus also serves as a structural component in many organic compounds within plants (Gardener et al., 1985). Potassium is crucial for enzyme activity, general metabolism, and leaf growth, particularly in relation to photosynthesis (Abd El-Hady et al., 2021). These findings are consistent with studies by Singh and Raghar (2000) and El-Metwaly (2020).

The application of Fulvic+75%NPK fertilizer significantly enhanced chlorophyll contents and nutrients percentage in leaves and tubers in addition to tuber quality. This may occur because fulvic acid enhance ion uptake in plant tissues (Chen et al., 2004), leading to increased ion percentages in leaves and tubers (Tables 4 and 5). Fulvic acid, with its low molecular weight and ability to bind elements and minerals, forms complexes that dissolve and mobilize easily (Farid et al., 2023; Makhlouf, 2023). The improved availability of elements under the experimental conditions (medium-fertile land) facilitates their uptake, positively impacting the studied elements. Fulvic acid is particularly effective in alleviating stress caused by fertilizer starvation, aiding mineral uptake, and positively contributing to tuber yield and quality (El-Metwaly, 2020). These findings align with studies conducted by Abou El Hassan and Husein (2016) and El-Hassanin et al. (2016).

Biochar has a positive effect on plant growth (Tolba et al., 2021; Khalil et al., 2023), mostly due to alterations in microbial communities that support beneficial rhizobacteria or fungi, as well as improving soil chemical and physical properties (Elad et al., 2011). Additionally, biochar improves dry matter production, likely through the immediate nutrient supply it provides (Silber et al., 2010; Elshony et al., 2019). Biochar can also raise plant tolerance towards drought stress conditions (Elsherpiny et al., 2023), enhancing nutrient accessibility, root colonization, ion uptake, and nutrient content (Yamato et al., 2006). The addition of biochar has been shown to increase productivity by improving nutrient retention, reducing leaching, and enhancing water holding capacity and cation exchange capacity (Graber et al., 2010; Carter et al., 2013; El-Metwaly, 2020).

Overall, these findings underscore the positive effects of soaking tubers, appropriate fertilization strategies, and the use of substances such as magnetized water, NPK fertilizers, fulvic acid, and biochar on potato cultivation, enhancing growth, yield, and quality.

Conclusion

The results indicate that there is a significant interaction between soaking potato tubers in magnetized water before planting and fertilizing with 100% NPK of the recommended dose or fulvic acid + 75% NPK of the recommended dose. This interaction positively influenced vegetative growth, yield, and tuber quality. However, further research is needed to explore the effects of soaking in magnetized water on anatomical characteristics in plant growth and the potential benefits of soaking tubers in various stimulants before planting.

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