

Responses of Growth, Yield, and Post-Harvest Quality of Onion Grown in Calcareous Soil to Bio-Stimulants, Starter Fertilizer, and Calcium Silicate

1. Responses of Post-Harvest Quality of Onion Grown in Calcareous Soil to Bio-Stimulants

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ABSTRACT

This study aimed to assess the pre-harvest impact of fulvic acid (FA; 0, 0.5, 1.0, and 1.5 g L⁻¹) and cyanobacteria (CB; 0, 2, 4, and 6 kg fed⁻¹) as bio-stimulants for improving the post-harvest quality of onion (*Allium cepa* L.) bulbs grown in calcareous soil. Two parallel field and storage experiments were conducted during the 2021/2022 growing season at the Experimental Farm of the City of Scientific Research and Technological Applications (SRTA-City), Borg El-Arab, Alexandria, and at a private farm in the Bangar El Sokar region, El-Behira Governorate, Egypt. Field experiments followed a split-plot system in a randomized complete block design with three replications, while storage experiments were arranged in a split-split-plot system in a randomized complete block design, with bulbs stored for 2, 4, and 6 months. The application of FA and CB significantly improved bulb storability compared with untreated controls. The combined treatment of FA at 1.0 g L⁻¹ with CB at 2–4 kg fed⁻¹ consistently minimized weight loss, mold incidence, and sprouting after six months of storage, whereas control bulbs exhibited the highest rates of deterioration.

These findings demonstrate that fulvic acid and cyanobacteria act as an effective, eco-friendly bio-stimulants to enhance the post-harvest quality of onion bulbs under Egyptian conditions. Their adoption offers a practical strategy to mitigate post-harvest losses and promote sustainable onion production systems.

Keywords: Onion, fulvic acid, cyanobacteria, bio-stimulants, storage.

INTRODUCTION

Onion (*Allium cepa* L.), belonging to the family *Alliaceae*, is one of the leading vegetable crops worldwide and the most important vegetable cash crop in Egypt, which is used for local consumption and exportation. In 2024, approximately 104,569 hectares were cultivated, yielding about 3.8 million tons, compared with 3.31 million tons produced from 94,457 hectares in 2021 (FAOSTAT, 2024). The national

average yield was 36.4 tons/ha, exceeding the regional average of 34 tons/ha (IndexBox, 2024).

Onion production also plays a significant role in Egypt's export sector. During 2023–2024, Egypt exported approximately 94,600 tons to the European Union, in addition to 22,000 tons of dried onions valued at 66 million USD, positioning Egypt as the third-largest global exporter with a 12% market share (Al Ghad, 2024 and Food Business MEA, 2024). These trends underline Egypt's growing importance in both fresh and processed onion markets.

A major challenge confronting onion cultivation in calcareous soils is a high content of calcium carbonate. This condition increases soil pH, which, either directly or indirectly, reduces organic matter and microbial biomass, while restricting the availability of essential nutrients, particularly phosphorus. This soil constraint poses a serious limitation to achieving optimal onion yield and quality, thereby necessitating targeted management strategies to enhance nutrient availability and improve productivity.

To address the challenges of onion production in calcareous soils, improving agricultural practices through the adoption of modern, safe, and cost-effective fertilization strategies is essential. One promising approach involves the application of natural bio-stimulants, such as fulvic acid (FA) and bio-fertilizers (e.g., cyanobacteria). Bio-stimulants comprise a broad group of substances and microorganisms that enhance plant growth, yield, and quality, while simultaneously improving tolerance to both biotic and abiotic stresses. They act by stimulating key physiological processes (Figure 1), including seed germination, root development, nutrient uptake, stomatal conductance, transpiration, and immune responses (Petropoulos *et al.*, 2020; Bertrand *et al.*, 2021 and Shahrajabian *et al.*, 2021). Moreover, bio-stimulants promote beneficial microbial activity in the soil, thereby improving nutrient cycling and soil structure, with significant implications for sustainable agricultural production. Six main categories of bio-stimulants have been identified:

DOI: 10.21608/asejaiqsae.2025.463354

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Received, September 25, 2025, Accepted, October 30, 2025.

microbial inoculants (such as cyanobacteria), humic substances (humic and fulvic acids), protein hydrolysates and amino acids, biopolymers, inorganic compounds, and seaweed extracts (Colla *et al.*, 2015 and Roupael & Colla, 2020).

Fulvic acid (FA), the second most important component of humic substances, has been widely recognized as an effective bio-stimulant that enhances plant growth and yield (Canellas *et al.*, 2015). It plays a vital role in regulating the retention and release of macro- and micronutrients, as well as to influence the bio-availability and mobility of organic compounds in soils (Hu *et al.*, 2019). FA is produced mainly by the biodegradation of lignin-containing plant organic matter (Malan, 2015). FA consists of a complex mixture of weak aliphatic and aromatic organic acids that remain soluble across all pH ranges. Owing to its relatively small molecular size, FA is more efficient in penetrating plant roots and foliage, and its biologically active molecules act rapidly to improve mineral uptake, stimulate plant growth, and strengthen plant tolerance to environmental stresses (Samavat and Samavat, 2014). In parallel, bio-fertilizers such as cyanobacteria represent another environmentally sustainable strategy to enhance soil fertility and crop productivity. Cyanobacteria are

autotrophic microorganisms, commonly found in in marine and freshwater, that often occur as unicellular forms or in colonies. Their ability to fix atmospheric nitrogen makes them valuable natural bio-fertilizers, improving soil fertility, nutrient availability, and consequently crop performance (Grzesik *et al.*, 2017; Ma *et al.*, 2019; Singh *et al.*, 2019 and Dineshkumar *et al.*, 2020). Beyond nutrient supply, cyanobacteria also contribute to long-term soil health and sustainability, providing a low-cost and eco-friendly alternative to chemical fertilizers (Giri *et al.*, 2019 and Kaur *et al.*, 2022).

Given the constraints of calcareous soils, particularly reduced nutrient availability and its adverse impact on onion productivity and quality, there is a pressing need for sustainable solutions. This study therefore investigates the use of modern bio-stimulants, specifically fulvic acid and cyanobacteria, as a strategy to enhance onion production and improve the post-harvest quality of bulbs under calcareous soil conditions. This research is a complementary part of a series of field studies, which were conducted to evaluate the effects of fulvic acid and cyanobacteria as bio-stimulants on the storage ability of onion bulbs.

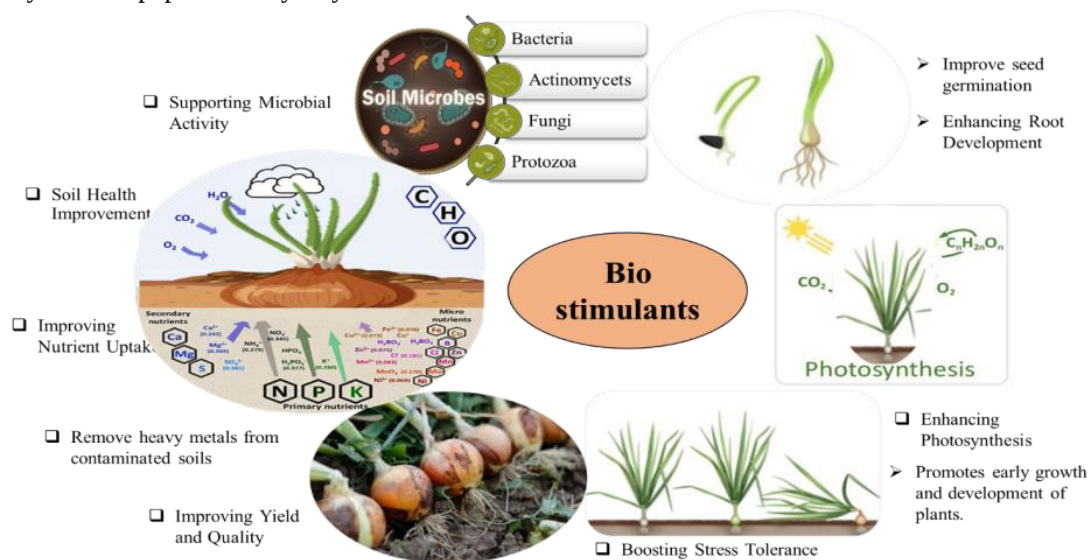


Figure 1. Schematic illustration showing the main effects of bio-stimulants on onion plants

MATERIALS AND METHODS

This study was conducted during the 2021/2022 growing season at two locations. The Experimental Farm of the City of Scientific Research and Technological Applications (SRTA-City), Borg El-Arab, Alexandria, Egypt, and a private farm in the Bangar El Sokar region, El-Behira Governorate, northern Egypt. Soil samples were collected from the 0–30 cm layer at both sites and analyzed at the Faculty of Agriculture, Alexandria University. The soils were classified as sandy loam. At SRTA-City, soil composition was 69% sand, 12% silt, and 19% clay, with pH 8.23, electrical conductivity (EC) 0.6 dS m⁻¹, organic matter 0.71%, and CaCO₃ 26.7%. At Bangar El Sokar, soil composition was 71% sand, 12% silt, and 17% clay, with pH 8.46, EC 0.4 dS m⁻¹, organic matter 0.76%, and CaCO₃ 25.4%.

Planting and agronomic practices:

Onion seedlings (cv. Giza 20) were transplanted during the first week of December 2021 at both locations, with three lines per row and 12 cm spacing between each two seedlings.

Treatments and experimental design:

Field experiment:

The field experiment consisted of 16 treatments, combining four fulvic acid (FA) levels (0, 0.5, 1.0, and 1.5 g L⁻¹) with four cyanobacteria levels (0, 2, 4, and 6 kg fed⁻¹). A split-plot system in a randomized complete blocks design (RCBD) with three replications was used. The fulvic acid levels were randomly assigned to main plots and cyanobacteria to subplots. Each sub-plot measured 6.3 m² (3 rows × 3 m × 0.70 m). Fulvic acid levels were applied twice: one week after transplanting as soil application (The required amount was dissolved in water at four concentrations 0, 0.5, 1.0, and 1.5 g L⁻¹ and a fixed volume of solution was applied around the plant bases along the rows to target the root zone) and 30 days later as foliar application. Cyanobacteria were applied as soil treatments at transplanting (Each concentration was thoroughly mixed with a portion of soil and then uniformly distributed along the planting rows near the plants, ensuring close contact with the root zone and then every 30 days (three applications in total). Standard cultural practices for onion production were followed throughout the season.

Post-harvest experiment:

Whole onion plants of each experimental unit were harvested on the first week of April 2022, in both locations. Harvested onion bulbs were cured for 21 days in a clean, shaded, well-ventilated, and dry room at a temperature of 25°C ± 2. After curing, forty bulbs were

randomly selected from each experimental unit and then sorted. The postharvest experiment included 48 treatments, which were the combinations of four levels of fulvic acid (0, 0.5, 1.0, and 1.5 g L⁻¹), four levels of cyanobacteria (0, 2, 4, and 6 kg fed⁻¹), and three storage durations (2, 4 & 6 months). The experimental design used was the split-split-plot system in a randomized complete blocks design with three replications. The fulvic acid levels were randomly arranged in the main plots, while cyanobacteria rates were randomly distributed in the sub-plots, while storage durations were randomly distributed in the sub-sub-plots. Each sub-sub-plot consisted of 40 bulbs; they were divided into two parts, where 20 bulbs were allocated to estimate the weight loss, and the other 20 bulbs were allocated for estimating other measurements.

Data recorded:

After curing (15 days), forty bulbs were randomly selected from each treatment to assess weight loss, rotting, and sprouting after 2, 4, and 6 months of storage.

Weight loss (%) was calculated by recording bulb weights at the start and end of each storage period, using the formula of Abubakar *et al.* (2019):

$$WL (\%) = (W_i - W_f) / W_i \times 100$$

Where W_i = initial bulb weight (g) and W_f = final bulb weight (g).

Rotting percentage (%) was determined as the proportion of bulbs showing decay symptoms (softening, discoloration, fungal growth) relative to the initial number of bulbs, multiplied by 100.

Sprouting percentage (%) was calculated as the proportion of bulbs with visible sprouts (≥ 2 mm) relative to the initial number of bulbs, multiplied by 100.

Statistical analysis:

All obtained data was subjected to the analysis of variance used in the previous design by the Co-State computer software program. The comparisons among means of the different treatments were carried out using the Revised LSD test at ($P > 0.05$).

RESULTS AND DISCUSSION

Effects of Fulvic acid (FA):

Data presented in Figure (2) demonstrate that the storage parameters of onion bulbs were markedly influenced by fulvic acid application in both experimental sites. The application of fulvic acid at 1.0 g L⁻¹ resulted in the lowest weight loss (8.53% and 9.62%) compared with the untreated control (11.26%

and 12.35%) at the first and second locations, respectively. In contrast, mold incidence and sprouting percentage were not affected by fulvic acid treatments. These results are consistent with the findings of Khalil *et al.* (2019), who reported that fulvic acid application enhances onion bulb storability by reducing weight loss through improved cell wall stability and decreased water loss.

Effect of Cyanobacteria:

Regarding soil inoculation with cyanobacteria, the results presented in Figure (3) indicate that onion bulbs from the untreated control exhibited the greatest weight

loss and sprouting percentage. In contrast, soil application of cyanobacteria at 4 kg fed⁻¹ significantly reduced sprouting (1.34% and 1.72%) and weight loss (9.35% and 10.44%) at the first and second locations, respectively. These effects may be attributed to the ability of cyanobacteria to produce bioactive compounds and phytohormones that enhance bulb quality and delay sprouting. Comparable findings were reported by El-Sawy *et al.* (2020), who demonstrated that cyanobacterial inoculation improved postharvest quality and reduced storage losses in onion bulbs.

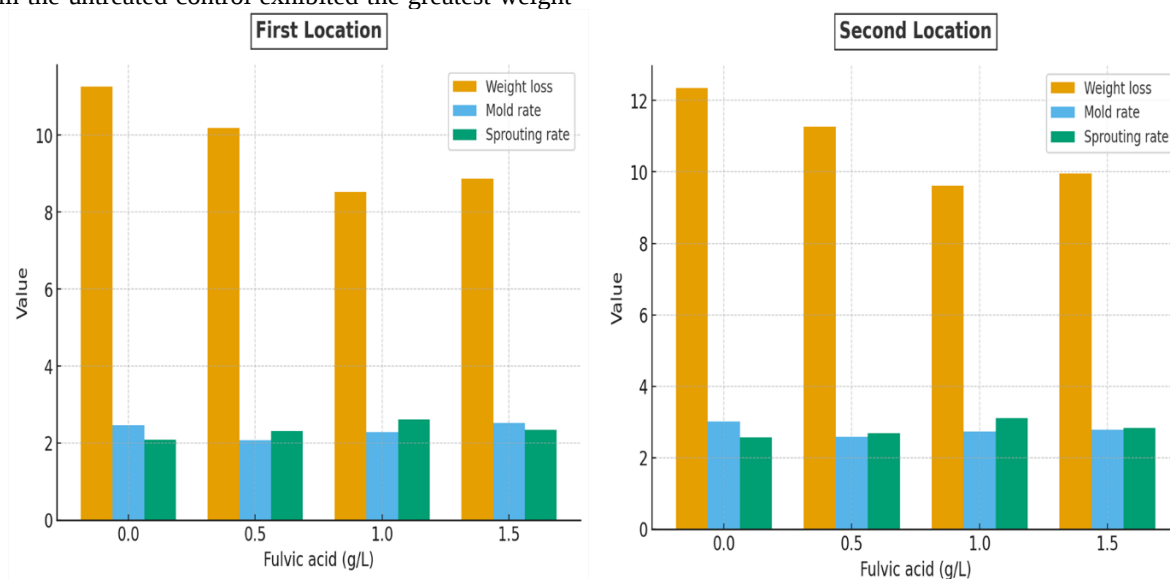


Figure 2. Effect of fulvic acid (g/L) on storage parameters of onion bulbs produced from both first and second locations (Borg El_Arabe and Bangar El Sokar)

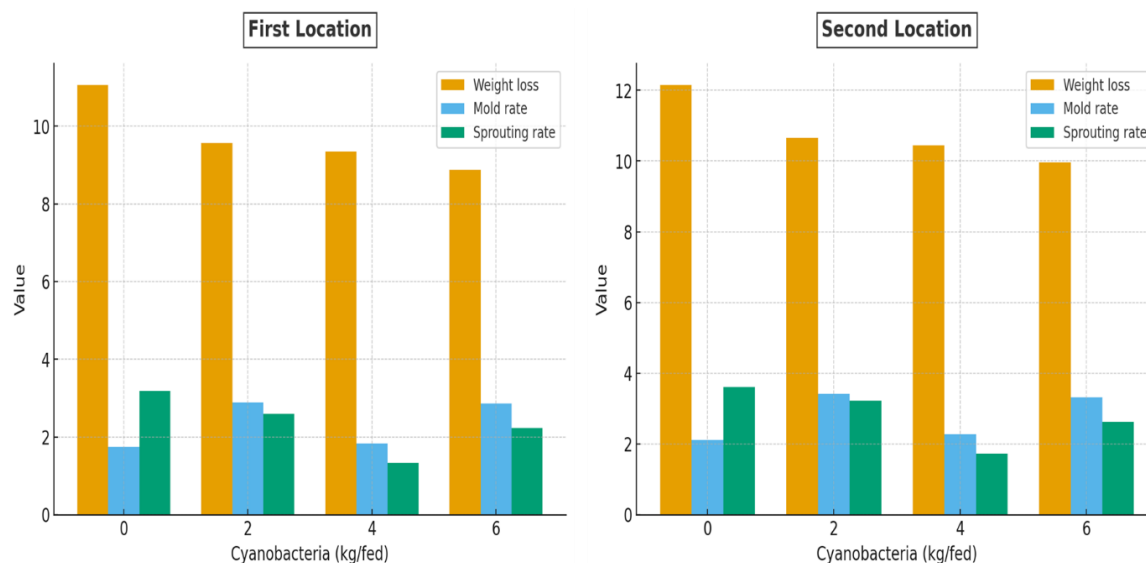


Figure 3. Effect of cyanobacteria (kg/fed) on storage parameters of onion bulbs produced from both first and second locations (Borg El_Arabe and Bangar El Sokar)

Effect of storage duration:

With respect to storage duration, the results presented in Figure (4) revealed that bulb weight loss decreased slightly with prolonged storage up to six months. In contrast, sprouting percentage increased markedly after six months, reaching 7.02% and 7.66% at the first and second locations, respectively. Mold incidence was highest after two months of storage and subsequently declined with extended storage. A similar trend was reported by Sharma and Singh (2018), who attributed the increase in sprouting under prolonged storage to hormonal changes within the bulbs, while noting that mold incidence typically peaks during the early stages of storage before diminishing thereafter.

Effect of interaction between fulvic acid and cyanobacteria:

Data presented in Table (1) demonstrate that the interaction between fulvic acid and cyanobacteria treatments exerted a significant influence on onion bulb storage parameters, including weight loss, mold incidence, and sprouting, across both experimental sites. The greatest weight losses were recorded in the untreated control, reaching 14.17% and 15.26% at the first and second locations, respectively. In contrast, the combined application of 0.5 g L⁻¹ fulvic acid with 6 kg fed⁻¹ cyanobacteria produced the lowest weight loss values (7.81% and 8.90%). This reduction may be attributed to the synergistic effects of fulvic acid, which enhances water retention and cell wall stability, and cyanobacteria, which improve bulb quality and delay senescence. These results are consistent with the findings of Khalil *et al.* (2019), who reported that fulvic

acid reduced postharvest weight loss in onion, and El-Sawy *et al.* (2020), who confirmed the role of cyanobacteria in minimizing storage losses

Regarding mold incidence, differences among treatment combinations were relatively minor and inconsistent. The lowest incidence was observed with 0.5 g L⁻¹ fulvic acid in the absence of cyanobacteria (0.78% and 1.01% at the first and second sites, respectively). On the other hand, some combinations, such as 1.0 g L⁻¹ fulvic acid with 6 kg fed⁻¹ cyanobacteria, were associated with comparatively higher mold rates (3.54% and 4.03%). These findings suggest that mold development during storage is influenced more strongly by prevailing environmental conditions than by the applied treatments, consistent with the observations of Sharma and Singh (2018).

As for sprouting character, the interaction effect was more pronounced. The combination of 1.5 g L⁻¹ fulvic acid with 4 kg fed⁻¹ cyanobacteria resulted in the lowest sprouting percentages (0.97% and 1.14% at the two sites, respectively). Conversely, higher sprouting levels were recorded with 1.0 g L⁻¹ fulvic acid combined with 2 kg fed⁻¹ cyanobacteria (4.21% and 4.94%). The suppression of sprouting under fulvic acid and higher cyanobacteria applications may be attributed to the accumulation of natural growth regulators and antioxidant compounds, which collectively delay dormancy release. Comparable reductions in sprouting due to bio-stimulant applications have been documented by Singh *et al.* (2021).

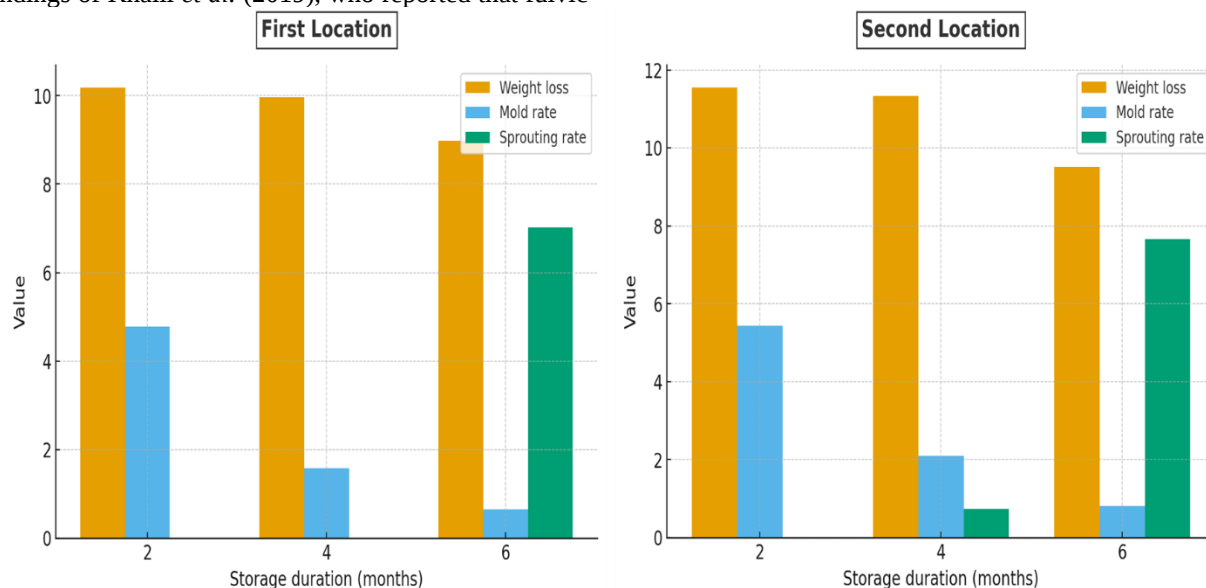


Figure 4. Effect of storage duration (months) on storage parameters of onion bulbs produced from both first and second locations (Borg El_Arabe and Bangar El Sokar)

Table 1. Storage parameters of onion bulbs as affected by fulvic acid and cyanobacteria interaction in first and second locations

Treatment combinations		Locations					
		First location			Second location		
Fulvic acid (g L ⁻¹)	Cyano bacteria (Kg fed-1)	Weight loss (%)	Mold rate	Sprouting rate	Weight loss (%)	Mold rate	Sprouting rate
0	0	14.17 a*	2.81 a-d	3.65 ab	15.26 a	3.44 ab	4.33 ab
	2	9.75 d-g	2.80 a-d	0.86 b	10.84 d-g	3.44 ab	1.11 c
	4	10.68 bcd	1.92 a-d	1.12 b	11.77 bcd	2.41 ab	1.60 bc
	6	10.44 cde	2.31 a-d	2.71 ab	11.53 cde	2.79 ab	3.22 abc
0.5	0	12.77 ab	0.78 d	2.47 ab	13.86 ab	1.01 b	2.65 abc
	2	12.05 abc	2.67 a-d	3.50 ab	13.14 abc	3.30 ab	3.94 abc
	4	8.10 fgh	2.64 a-d	1.69 ab	9.19 fgh	3.27 ab	2.13 abc
	6	7.81 gh	2.23 a-d	1.56 ab	8.90 gh	2.79 ab	2.02 abc
1	0	8.84 d-h	0.90 cd	2.38 ab	9.93 d-h	1.21 b	3.01 abc
	2	7.08 h	2.83 a-d	4.21 a	8.17 h	3.31 ab	4.94 a
	4	9.96 c-f	1.88 a-d	1.60 ab	11.05 c-f	2.41 ab	2.02 abc
	6	8.24 fgh	3.54 a	2.30 ab	9.33 fgh	4.03 a	2.47 abc
1.5	0	8.46 e-h	2.51 a-d	4.21 a	9.55 e-h	2.78 ab	4.47 ab
	2	9.37 d-g	3.26 abc	1.84 ab	10.46 d-g	3.64 ab	2.91 abc
	4	8.64 d-h	0.93 bcd	0.97 b	9.73 d-h	1.03 b	1.14 c
	6	9.00 d-h	3.38 ab	2.35 ab	10.09 d-h	3.66 ab	2.81 abc

*Values marked with same alphabetical letter(s), within a comparable group of means, do not Significantly differ, using Revised L.S.D. test at 0.05 level.

Effect of interaction between fulvic acid and storage duration:

Data in Table (2) demonstrate that the interaction between fulvic acid application rates and storage duration exerted a significant influence on onion bulb storability across both experimental sites. The lowest weight loss was consistently recorded in bulbs from plants treated with 1.0 g L⁻¹ fulvic acid after six months of storage (6.84% and 7.37% at the first and second locations, respectively), whereas the untreated control exhibited markedly higher losses (11.14% and 11.67%). These results highlight the crucial role of fulvic acid in reducing postharvest weight loss, likely through improved water retention capacity and maintaining of cellular membranes. Similar reductions in bulb weight loss following fulvic acid application were previously reported by Khalil *et al.* (2019).

Regarding the mold incidence, the highest values were observed after two months of storage under the 1.5 g L⁻¹ fulvic acid treatment (6.37% and 6.85% at the first and second locations, respectively), whereas the lowest values were detected at six months under the same

treatment (0.05% and 0.03%). These results indicate that mold infection is most pronounced during the early stages of storage but declines thereafter, corroborating the findings of Sharma and Singh (2018), who reported that mold incidence typically peaks early and diminishes with extended storage duration.

For sprouting, no visible emergence was recorded in any treatment during the first four months of storage; however, sprouting increased markedly after six months. The highest sprouting percentages (7.87% and 8.58%) were associated with 1.0 g L⁻¹ fulvic acid, followed closely by 1.5 g L⁻¹ (7.03% and 7.74%) at the two locations. This pattern reflects the natural physiological release from dormancy with prolonged storage. The relatively higher sprouting under fulvic acid treatments may be attributed to its stimulatory effects on metabolic activity, consistent with the observations of Singh *et al.* (2021), who demonstrated that bio-stimulants can accelerate dormancy breaking and enhance sprouting in onion bulbs.

Table 2. Storage Parameters of onion plants as affected by Fulvic acid and Storage duration interaction in first and second locations

Treatment combinations		Locations					
		First location			Second location		
Fulvic acid (g L ⁻¹)	Storage duration (month)	Weight loss (%)	Mold rate	Sprouting rate	Weight loss (%)	Mold rate	Sprouting rate
0	2	10.28 bcd*	4.78 ab	0.00 b	11.65 bc	5.65 ab	0.00b
	4	12.36 a	1.51 d	0.00 b	13.73 a	2.03 cde	0.80b
	6	11.14 ab	1.09 d	6.26 a	11.67 bc	1.38 de	6.90a
0.5	2	10.72 abc	3.56 bc	0.00 b	12.09 ab	4.12 bc	0.00b
	4	9.63 bcd	1.95 cd	0.00 b	11.00 bc	2.67 cd	0.62b
	6	10.20 bcd	0.73 d	6.92 a	10.73 bc	0.99 de	7.43a
1	2	9.93 bcd	4.43 ab	0.00 b	11.30 bc	5.14 ab	0.00b
	4	8.82 de	1.72 cd	0.00 b	10.19 c	2.24 cde	0.75b
	6	6.84 f	0.71 d	7.87 a	7.37 d	0.84 de	8.58a
1.5	2	9.80 bcd	6.37 a	0.00 b	11.17 bc	6.85 a	0.00b
	4	9.07 cde	1.13 d	0.00 b	10.44 bc	1.47 de	0.76b
	6	7.75 ef	0.05 d	7.03 a	8.28 d	0.03 e	7.74a

*Values marked with same alphabetical letter(s), within a comparable group of means, do not Significantly differ, using Revised L.S.D. test at 0.05 level.

Effect of interaction between cyanobacteria and storage duration:

The interaction between cyanobacteria application and storage duration exerted a significant influence on onion bulb storage parameters across both experimental sites (Table 3). The greatest weight loss occurred in the untreated control (0 kg fed⁻¹ cyanobacteria) after four months of storage, reaching 11.92% and 13.29% at the first and second locations, respectively. Conversely, the lowest weight loss was observed at the highest cyanobacteria level (6 kg fed⁻¹) after six months of storage, with values of 7.53% and 8.06% at the respective locations

Mold incidence followed a distinct temporal trend. The maximum values (6.78% and 7.49%) were recorded with 6 kg fed⁻¹ cyanobacteria after two months of storage, whereas the lowest incidence (0.13% and 0.10%) occurred with the same treatment after six months, suggesting that cyanobacteria application provided a strong protective effect over time

For sprouting, the untreated control exhibited the highest values after six months (9.54% and 10.25%), while cyanobacteria application consistently suppressed

sprouting. At 6 kg fed⁻¹, sprouting remained comparatively low (6.69% and 7.34%) at both locations after six months.

These findings highlight that cyanobacteria played a positive role in reducing weight loss and sprouting percentage of onion bulbs while minimizing mold incidence during storage. This could be attributed to their ability to enhance nutrient uptake, activate antioxidant defense systems, and release bioactive metabolites with antimicrobial properties. Abd El-Moniem *et al.* (2020) reported that cyanobacteria biofertilization reduced postharvest losses in onion bulbs by maintaining bulb firmness and delaying senescence. Similarly, Mohamed and Abo Sedera (2018) demonstrated that cyanobacterial extracts possess antifungal properties, reducing storage diseases in onion bulbs. Additionally, Yassen *et al.* (2017) indicated that cyanobacteria treatments extended bulb dormancy by modulating hormonal balance and decreasing ethylene biosynthesis, which helps in reducing sprouting.

Table 3. Storage parameters of onion plants as affected by cyanobacteria and storage duration interaction in first and second locations

Treatment combinations		Locations					
		First location			Second location		
Cyano bacteria (Kg fed ⁻¹)	Storage duration (month)	Weight loss (%)	Mold rate	Sprouting rate	Weight loss (%)	Mold rate	Sprouting rate
0	2	11.17 ab*	3.77 bc	0.00 d	12.54 a	4.33 bc	0.00 d
	4	11.92 a	0.77 ef	0.00 d	13.29 a	0.98 de	0.59 d
	6	10.09a-d	0.71 ef	9.54 a	10.62 bcd	1.03 de	10.25 a
2	2	8.78 cde	5.41 ab	0.00 d	10.15 bcd	6.29 ab	0.00 d
	4	10.25 a-d	2.42 cde	0.00 d	11.62 abc	2.99 cd	1.16 d
	6	9.65 bcd	0.84 ef	7.81 ab	10.18 bcd	1.00 de	8.52 ab
4	2	10.21 a-d	3.17 cd	0.00 d	11.58 abc	3.65 c	0.00 d
	4	9.17 cde	1.46 def	0.00 d	10.54 bcd	2.09 cde	0.62 d
	6	8.66 de	0.90 ef	4.03 c	9.19 de	1.11 de	4.55 c
6	2	10.56 abc	6.78 a	0.00 d	11.93 ab	7.49 a	0.00 d
	4	8.53 de	1.68 def	0.00 d	9.90 cde	2.36 cde	0.56 d
	6	7.53 e	0.13 f	6.69 b	8.06 e	0.10 e	7.34 b

*Values marked with same alphabetical letter(s), within a comparable group of means, do not significantly differ, using Revised L.S.D. test at 0.05 level.

Effect of interaction among fulvic acid, cyanobacteria and storage duration:

Data in Table (4) demonstrate that the interaction between fulvic acid and cyanobacteria markedly influenced onion bulb storability across both experimental sites. The highest weight loss was recorded under the untreated control after four months of storage, reaching 17.37% and 18.74% at the first and second locations, respectively. In contrast, the lowest values were observed with the combined application of fulvic acid (1.0 g L⁻¹) and cyanobacteria (6 kg fed⁻¹) after six months, recording only 6.74% and 7.27% at the two locations. These findings highlight the synergistic role of fulvic acid and cyanobacteria in substantially mitigating postharvest weight loss compared with the control.

Mold incidence followed a variable trend, with the maximum rates observed under fulvic acid (1.0 g L⁻¹) combined with cyanobacteria (6 kg fed⁻¹) after two months of storage (8.78% and 9.73%). Conversely, complete suppression of mold (0.00%) was achieved in several treatments, particularly under fulvic acid (1.5 g L⁻¹) combined with cyanobacteria (0–4 kg fed⁻¹) after six months. This suggests that both agents exhibit antifungal potential, which becomes more pronounced at higher application levels and prolonged storage.

Sprouting percentage increased progressively with storage duration, peaking at 12.63–12.64% in the first location and 13.40–13.41% in the second location under fulvic acid (1.0–1.5 g L⁻¹) without cyanobacteria after six months. By contrast, the lowest sprouting (0.00%) was recorded under fulvic acid (0.5 g L⁻¹) combined with cyanobacteria (6 kg fed⁻¹) after four months, along with several other combinations during earlier storage periods.

The results clearly indicate that integrating fulvic acid with cyanobacteria is more effective than their individual application in reducing weight loss, suppressing sprouting, and limiting mold incidence during onion storage. This synergistic effect can be attributed to improvements in bulb nutritional status, reinforcement of antioxidant defense mechanisms, and induction of natural resistance against storage pathogens. Comparable findings were reported by Khalil *et al.* (2019), who showed that fulvic acid delayed senescence and maintained bulb firmness, and by Abd El-Moniem *et al.* (2020), who demonstrated the positive impact of cyanobacteria biofertilization on postharvest quality. Furthermore, Yassen *et al.* (2017) confirmed that integrating organic and biofertilizers enhances bulb dormancy and suppresses sprouting, thereby minimizing storage losses.

Table 4. Storage parameters of onion bulbs as affected by fulvic acid, cyanobacteria and storage duration interaction in first and second locations

Treatment combinations			locations					
			First location			Second location		
Fulvic acid (g L ⁻¹)	Cyano Bacteria (Kg fed ⁻¹)	Storage duration (month)	Weight loss (%)	Mold rate	Sproutin g rate	Weight loss (%)	Mold rate	Sprouting rate
0	0	2	13.46 bc*	4.69 c-g	0.00 e	14.83 bc	5.32 b-g	0.00 i
		4	17.37 a	1.28 f-i	0.00e	18.74 a	1.60 e-i	1.26 ghi
		6	11.66 b-g	2.46 e-i	10.96ab	12.19b-g	3.41 d-i	11.73 ab
	2	2	4.76 o	5.23 a-f	0.00e	6.13 l	6.18 a-e	0.00 i
		4	11.94 b-f	3.18 d-i	0.00e	13.31bcd	4.13 c-i	0.00 i
		6	12.54bcd	0.00 i	2.57de	13.07 bcd	0.00 i	3.34 e-i
	4	2	10.81 c-j	3.47 d-i	0.00e	12.18 b-g	4.42 c-i	0.00 i
		4	10.20 c-k	0.39 hi	0.00e	11.57 b-i	0.70 hi	1.17 ghi
		6	11.03 b-j	1.89 e-i	3.36cde	11.56 b-i	2.12 d-i	3.62 d-i
	6	2	12.08 b-f	5.72 a-e	0.00e	13.45 bcd	6.67 a-d	0.00 i
		4	9.91 c-m	1.21 f-i	0.00e	11.28 c-i	1.70 e-i	0.77 hi
		6	9.34 d-n	0.00 i	8.13abc	9.87 d-l	0.00 i	8.90 a-d
0.5	0	2	12.08 b-f	1.82 e-i	0.00e	13.45 bcd	2.14 d-i	0.00 i
		4	11.45 b-i	0.13 hi	0.00e	12.82 b-e	0.19 hi	0.00 i
		6	14.79 ab	0.38 hi	7.42bcd	15.32 ab	0.70 hi	7.94 b-e
	2	2	12.16 b-e	3.45 d-i	0.00e	13.53 bcd	4.09 c-i	0.00 i
		4	11.98 b-f	3.82 c-i	0.00e	13.35 bcd	4.77 c-h	0.81 hi
		6	12.01 b-f	0.74 ghi	10.50ab	12.54 b-f	1.06 f-i	11.02 abc
	4	2	8.68 e-n	4.13 c-h	0.00e	10.05 d-k	4.77 c-h	0.00 i
		4	7.78 h-o	2.11 e-i	0.00e	9.15 e-l	3.06 d-i	0.81 hi
		6	7.83 h-o	1.68 e-i	5.06cd	8.36 h-l	1.99 e-i	5.57 d-h
	6	2	9.96 c-l	4.84 b-f	0.00e	11.33 c-i	5.47 b-f	0.00 i
		4	7.29 j-o	1.74 e-i	0.00e	8.66 g-l	2.69 d-i	0.85 hi
		6	6.18 mno	0.11 hi	4.68 cde	6.71 kl	0.20 hi	5.20 d-i
1	0	2	10.67 c-j	1.43 f-i	0.00e	12.04 b-h	1.75 e-i	0.00 i
		4	9.66 d-n	1.26 f-i	0.00e	11.03 d-i	1.88 e-i	1.11 ghi
		6	6.21 l-o	0.00 i	7.15 bcd	6.74 kl	0.00 i	7.92 b-e
	2	2	7.36 j-o	3.76 c-i	0.00e	8.73 g-l	4.71 c-h	0.00 i
		4	7.77 h-o	2.12 e-i	0.00e	9.14 e-l	2.30 d-i	1.40 ghi
		6	6.09 no	2.62 e-i	12.64a	6.62 kl	2.94 d-i	13.41 a
	4	2	11.47 b-h	3.74 c-i	0.00e	12.84 b-e	4.39 c-i	0.00 i
		4	10.10 c-k	1.88 e-i	0.00e	11.47 c-i	2.52 d-i	0.49 hi
		6	8.32 f-o	0.02 i	4.80 cde	8.85 f-l	0.34 hi	5.57 d-h
	6	2	10.23 c-k	8.78 ab	0.00e	11.60 b-i	9.73 ab	0.00 i
		4	7.74 h-o	1.63 f-i	0.00e	9.11 e-l	2.26 d-i	0.00 i
		6	6.74 k-o	0.21 hi	6.90 bcd	7.27 jkl	0.10 i	7.42 b-f
1.5	0	2	8.48 e-o	7.15 a-d	0.00e	9.85 d-l	8.10 abc	0.00 i
		4	9.21 d-n	0.39 hi	0.00e	10.58 d-j	0.24 hi	0.00 i
		6	7.70 i-o	0.00 i	12.63a	8.23 i-l	0.00 i	13.40 a
	2	2	10.85 c-j	9.21 a	0.00e	12.22 b-g	10.16 a	0.00 i
		4	9.31 d-n	0.56 hi	0.00e	10.68 d-j	0.77 ghi	2.44 f-i
		6	7.95 g-o	0.00 i	5.53cd	8.48 g-l	0.00 i	6.30 c-g
	4	2	9.89 c-m	1.33 f-i	0.00e	11.26 c-i	1.02 f-i	0.00 i
		4	8.59 e-n	1.45 f-i	0.00e	9.96 d-k	2.08 d-i	0.00 i

	6	7.45 j-o	0.00 i	2.91de	7.98 i-l	0.00 i	3.43 e-i
	2	9.96 c-l	7.79 abc	0.00e	11.33 c-i	8.11 abc	0.00 i
6	4	9.15 d-n	2.14 e-i	0.00e	10.52 d-j	2.77 d-i	0.62 hi
	6	7.88 h-o	0.21 hi	7.06 bcd	8.41 h-l	0.11 i	7.83 b-e

*Values marked with same alphabetical letter(s), within a comparable group of means, do not significantly differ, using Revised L.S.D. test at 0.05 level.

CONCLUSION AND RECOMMENDATIONS

The present study demonstrates that fulvic acid and cyanobacteria act as effective bio-stimulants for enhancing onion bulb storability under calcareous soil conditions. Application of fulvic acid at 1.5 g L⁻¹ and cyanobacteria at 6 kg fed⁻¹ significantly reduced postharvest losses by minimizing weight loss, mold incidence, and sprouting, while simultaneously improving bulb quality and defense responses. Notably, the combined treatment of fulvic acid (1.0 g L⁻¹) with cyanobacteria (6 kg fed⁻¹) provided the most consistent benefits, maintaining bulb quality and extending storability for up to six months across both experimental sites. These findings underscore the potential of integrating fulvic acid and cyanobacteria into onion production and storage systems as an eco-friendly and sustainable strategy to prolong shelf life and mitigate postharvest losses, offering a viable alternative to conventional chemical treatments. Future research should focus on evaluating the scalability of these bio-stimulants under commercial storage conditions and their economic feasibility to promote broader adoption in onion supply chains.

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الملخص العربي

استجابة نباتات البصل النامية في التربة الجيرية لبعض المحفزات العضوية والحيوية وإضافة الاسمدة البادئة والرش بسيليكا الكالسيوم

1 . تأثير السيانونيكتريا وحمض الفولفيك كمحفزات حيوية على القدرة التخزينية لدرنات البصل

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انخفضت نسبة الإصابة بالعفن بنحو ٥٠%، مما يعكس تعزيز المقاومة الطبيعية للأبصال. كما أظهرت نفس المعاملة أقل معدلات للتزريع بانخفاض قدره 60% مقارنة بالكنترول بعد نفس المدة. أما المعاملات الفردية، فقد أدى حمض الفولفيك عند ١.٥ جم/لتر إلى خفض واضح في الفقد بالوزن، بينما كانت السيانونيكتريا عند ٦ كجم/فدان الأكثر كفاءة في تقليل التزريع. في المقابل، سجلت أبصال الكنترول أعلى معدلات تدهور تخزيني، حيث بلغت نسبة الفقد في الوزن ١٢%، والتزريع أكثر من ٩%، والعفن ٣-٥%.

تؤكد هذه النتائج أن حمض الفولفيك والسيانونيكتريا يُعدّان محفزات حيوية طبيعية وآمنة تسهم في تحسين جودة أبصال البصل وتقليل الفاقد بعد الحصاد، ويوصى بتطبيقهما في برامج إنتاج وتخزين البصل لتحقيق استدامة زراعية صديقة للبيئة.

الكلمات المفتاحية: البصل، حمض الفولفيك، السيانونيكتريا، المحفزات الحيوية، التخزين.

هدفت هذه الدراسة إلى تقييم التأثيرات قبل الحصاد لكل من حمض الفولفيك (٠، ٠.٥، ١.٠، و ١.٥ جم/لتر) والسيانونيكتريا (٠، ٢، ٤، و ٦ كجم/فدان) كمحفزات حيوية لتحسين جودة أبصال البصل المزروعة في تربة جيرية. أُجريت تجربتان متوازيتان، حقلية وتخزينية، خلال الموسم الزراعي 2021/2022 في المزرعة التجريبية لمدينة الأبحاث العلمية والتطبيقات التكنولوجية (SRTA-City) ببرج العرب - الإسكندرية، وفي مزرعة خاصة بمنطقة بنجر السكر، محافظة البحيرة، مصر. نُفذت التجارب الحقلية وفق نظام القطع المنشقة في تصميم القطاعات العشوائية الكاملة بثلاث مكررات، بينما تم تنفيذ التجارب التخزينية وفق نظام القطع المنشقة مرتين بنفس التصميم، حيث حُزنت الأبصال لمدة شهرين، أربعة، وستة أشهر.

أظهرت النتائج أن المعاملة المشتركة من حمض الفولفيك بتركيز 1.0 جم/لتر مع السيانونيكتريا بمعدل 4-2 كجم/فدان حققت أفضل أداء، إذ خفّضت الفقد في الوزن بنسبة ٣٥-٤٠% مقارنة بالكنترول بعد ستة أشهر من التخزين، كما