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INTEGRATED EFFECTS OF MICROBIAL GIBBERELLIC ACID AND VITAMINS ON NUTRIENT UPTAKE, ONION AND WATER PRODUCTIVITY, AND CALCAREOUS SOIL FERTILITY

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ABSTRACT: Global food security is at risk because of increased environmental stress, reduced acreage, and decreased crop yields. Thus, microbial technologies are becoming vital for sustainable agriculture. There is little information about the effect of microbial gibberellic acid (GA_3) and vitamins on water and onion productivity and nutrient status in soil and plants. Two field trials were carried out on a calcareous sandy soil farm during two consecutive winter seasons. Two treatments were in the main plot (without and with microbial GA_3), and six were in the sub-plot (control, chemical thiamine, microbial ascorbic acid, chemical ascorbic acid microbial riboflavin, and chemical riboflavin). The data clarified that the foliar applications of microbial GA_3 or vitamin treatments significantly improved onion productivity (total yield of fresh and dried bulbs, dry matter percentage, protein yield, NPK uptake) water productivity (irrigation water use efficiency and water use efficiency for total dry and fresh bulb yield) and improved or maintains soil fertility (available NPK, pH, EC and OM content) in both seasons. The biological ascorbic acid treatment performed better than the other vitamin treatments in most of the tested parameters. Foliar application of microbial GA_3 plus vitamins, particularly biological ascorbic acid and biological riboflavin, resulted in a greater improvement in the parameters that were evaluated. Microbial GA_3 combined with microbial vitamins as a foliar spray is an effective, eco-friendly, and low-cost plant biostimulator that can be safely used in low-fertility soils to enhance onion yield, water productivity, and enhance or maintain soil fertility.

Keywords: Vitamin C., Vitamin B, Onion dry yield. Available nutrient. Sandy soil.

INTRODUCTION

Globally, sandy soils are found on over nine hundred million hectares, particularly in semi-arid and arid areas (Yost & Hartemink, 2019; Zahran, 2025). Sandy soils face significant productivity challenges due to suboptimal physical, chemical, and biological characteristics, including inadequate organic matter percentage, insufficient nutrient and water retention capabilities, restricted capacity for cation exchange, diminished biotic diversity, and high rates of hydraulic conductivity, which requires large external inputs to support agricultural capacity (Yost & Hartemink, 2019; Zahran, 2025). On the other hand, calcareous soil is defined as one that contains $CaCO_3$, which negatively affects the chemical, physical, or biological properties important for plant growth (Abdelaal *et al.*, 2025; Zahran, 2025). More than 30% of the Earth's surface, by calcium carbonate concentrations ranging from < 5% to 95% (Zahran *et al.*, 2020; Abdelaal *et al.*, 2025). These soils make up around 0.27 million hectares, or 25 to 30% of Egypt's total land area (Zahran *et al.*, 2020; Abdelaal *et al.*, 2025). As in our current study, calcareous soils often combine with sandy textures to form calcareous sandy soils, resulting in more complex physical, chemical, and biological problems. This is common in hyper-arid, arid, and semi-arid regions, as Egypt, that need a significant increase in crop productivity to be at the front with rapid population growth, decreasing agricultural land area, and declining soil productivity caused by

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degradation, desertification, and erosion (Omran & Negm, 2020). Therefore, converting sandy calcareous soils into agriculturally productive ones is a priority for scientific research efforts, particularly for cultivating strategic crops like onions, which have demonstrated success in Egypt’s newly reclaimed soils and similar regions around the world.

In Egypt, onions rank third in terms of strategic vegetable crops after tomatoes and potatoes. When compared to comparable products in other nations, Egyptian onions-dry, fresh, and processed-are one of the primary sources of hard currency because of their significant competitive edge, especially with high quality, high nutritional value, and pungent power (Sorour *et al.*, 2025; Zahran, 2025). Recently, it has been a great trend to use some substances to resist unfavorable environmental conditions. But the production of plant growth enhancers such as vitamins by chemical synthesis raises a number of economic, environmental, and safety issues, such as high energy consumption, high cost, use of non-renewable chemical ingredients, production of hazardous waste, and toxic residues (Acevedo-Rocha *et al.*, 2019). The safe, affordable, environmentally friendly, and sustainable method for producing these goods from an economic and environmental perspective is microbial production. Therefore, we suggest treating onion plants with one of the microbially synthesized gibberellins (gibberellic acid) and microbial vitamins (C and B), especially given the limited information about the interaction between microbial vitamins and gibberellic acid on onions.

Gibberellins are one of the plant hormones; they are natural carboxylic acids combined with several plant growth and development operations (Hussien *et al.*, 2018). Only GA_1, GA_3, GA_4, and GA_7 are bioactive and well-known gibberellins, which are generated by plants, fungi, and even bacteria (Sponsel & Hedden, 2004; Mohamed & Mahmoud, 2018). Gibberellic acid (GA_3) is a natural endogenous plant growth regulator (Thuc *et al.*, 2021). It is produced naturally in germinated seed embryos and new leaves (Sponsel & Hedden, 2004). Microorganisms, particularly endophytic bacteria and fungi, are a prospective commercial source for the synthesis of microbial GA_3 (Camara *et al.*, 2018). Filamentous fungi are the largest producers of GA_3 associated with the genus *Fusarium*, which includes *moniliforme, glutinans, oxysporum, chlamydosporum, verticilloides, solani, sacchari, and konzum* (Mohamed & Mahmoud, 2018; Mahmoud *et al.*, 2021). The chemical formula for gibberellic acid is $C_{19}H_{22}O_6$ with a molecular weight of 346.37 g mol^{-1} (Camara *et al.*, 2018). Gibberellic acid can be added externally as a plant growth regulator in the form of seed soaking (Arun *et al.*, 2017; Rashad, 2020), foliar spray (Hussien *et al.*, 2018; Thuc *et al.*, 2021; Farad *et al.*, 2025), and soil application (Haifaa & Moses, 2022). On the one hand, researchers have found that applying gibberellic acid externally at the right dosage and right time boosts plant growth, chemical composition, nutrient absorption, and production for a variety of different vegetable and field crops like onion (Sorour *et al.*, 2025), potato (Caliskan *et al.*, 2021), cucumber (Pal *et al.*, 2016), lettuces (Le *et al.*, 2021), rice (Haifaa & Moses, 2022), maize (El-Kamar, 2013), sweet sorghum (El-Kady *et al.*, 2019), lentil (Hussien *et al.*, 2018) and mungbean (Islam *et al.*, 2021). On the opposite side, several researchers explained that gibberellic acid can raise the plant's ability to withstand abiotic stress conditions such as salinity (El-Kamar, 2013), drought (Rady *et al.*, 2021), and heavy metals (Emamverdian *et al.*, 2020).

Vitamins are essential organic nutrients for the overall development of organisms. They are one of the most important organic substances that stimulate plant growth, act as cofactors for several key enzymes engaged in metabolism, and play a significant role in the metabolic activities of plants (Ghaffar *et al.*, 2019; Younis *et al.*, 2020). Exogenous processing of vitamins has a positive effect on plant growth, protein biosynthesis, and the productivity of various crops, especially as it protects the plant from the harmful effects of abiotic stress generated by various environmental stresses (El-Bassiouny & Sadak, 2015; Amjad *et al.*, 2021; Jabeen *et al.*, 2021). Water-soluble vitamins C and B have significant antioxidant potential (Abdel-Hafeez *et al.*, 2019; Fitzpatrick & Chapman, 2020). Vitamin C or ascorbic acid ($C_6 H_8 O_6$ with molecular weight of 176.12 g mol^{-1}), is a major non-enzymatic antioxidant in plants (Hassan *et al.*, 2021). External addition of ascorbic acid (AsA) can be made by foliar spraying (Abdel Hafeez and Ewees, 2018; Saudy *et al.*, 2023), seed soaking (El Azab, 2012), and soil application (Fawy *et al.*, 2016). Ascorbic acid can be applied to increase a plant's capacity to tolerate biotic and abiotic stress conditions, including salt (El-Bassiouny and Sadak 2015; Baddour *et al.*, 2017; Hassan *et al.*, 2021), drought (Abdo *et al.*, 2018; Kotb *et al.*, 2021; Saudy *et al.*, 2023), and heavy metals (Alamri *et al.*, 2018), thus increasing the yield of crops under stress. Ascorbic acid is commonly produced by yeasts, particularly *Saccharomyces cerevisiae* and *Zygosaccharomyces bailii*, using sorbose, galactose, and glycerol media (Sauer *et al.*, 2004). *Bacillus endophyticus*, *Ketogulonigenium vulgare*, and *Gluconobacter oxydans* produce ascorbic acid on sorbose medium (Chen *et al.*, 2023). Finally, it should be highlighted that studies have generally shown that administering ascorbic acid externally at the proper dose improves plant growth, nutrient absorption, chemical composition, and yield for a range of different field crops and vegetables, including tomato (Abdel Hafeez & Ewees, 2018), eggplant (Fouda & Abd-Elhamied, 2017), cabbage (Mosa & Ramadan, 2011), faba bean (Fawy *et al.*, 2016), Sunflower (Abdel-Hafeez *et al.*, 2019), and flax (El-Bassiouny & Sadak, 2015). In plants, vitamin B complex is a group of seven vitamins: vitamin B1 or thiamine, vitamin B2 or riboflavin, vitamin B3 or niacin, vitamin B5 or pantothenic acid, vitamin B6 or pyridoxine, vitamin B7 or biotin, and vitamin B9 or folic acid (Roje, 2007). On the other hand, plants cannot synthesize B12 (cyanocobalamin) and thus plant foods are typically fully devoid of or have very low concentrations of this vitamin (Mozafar, 1994). In our study, we will only consider vitamins B1 and B2. The chemical formula for thiamine and riboflavin is $C_{12}H_{17}N_4O$ and $C_{17}H_{20}N_4O_6$, with molecular weights of 233.30 and 376.37 g mol^{-1}, respectively (Roje, 2007; Fitzpatrick & Chapman, 2020). Metabolically modified strains of *Bacillus subtilis* and *Ashbya gossypii* are currently used in large-scale fermentations for bacterial riboflavin production (Acevedo-Rocha *et al.*, 2019). On the other hand, microorganisms do not often create microbial thiamine, which is generated by a genetic transformation process using E. coli (Cardinale *et al.*, 2017). Thiamine or riboflavin acid can be given externally to plants to regulate how they develop. These external additions of B1 or B2 vitamins can be done by foliar spraying (Darwish *et al.*, 2017; Aminifard *et al.*, 2018) and seed soaking (Sahu *et al.*, 1993; Pradi-Vendruscolo & Seleguini, 2020). When used, vitamin B1 can improve a plant's ability to withstand abiotic stress situations like salinity (Hamada & Al-Hakimi, 2009; Pradi-Vendruscolo & Seleguini, 2020), drought (Ghaffar *et al.*, 2019; Amjad *et al.*, 2021; Jabeen *et al.*, 2021), and heavy metals (Al-Hakimi & Hamada 2011; Sanjari, *et al.*, 2019; Atif, *et al.*, 2022), thus increasing the yield of crops under stress. Similar results on vitamins B2 improve a plant's ability to withstand abiotic stress situations like as salinity (Darwish, 2017). On the other side, researchers have typically discovered that administering thiamine topically at the proper dose increases plant growth, chemical properties, absorption of nutrients, and yield for a variety of fields and vegetables and crops, such as white clover (Ghaffar *et al.*, 2019), faba bean (Younis *et al.*, 2020), maize (Sahu *et al.*, 1993), sweet maize (Pradi-Vendruscolo & Seleguini, 2020), and wheat (El-Bassiouny *et al.*, 2023). Moreover, foliar application of riboflavin enhanced the yield and yield components of Tecoma (Darwish *et al.*, 2017) and grapevines (Belal *et al.*, 2016). Also, Jiadkong *et al.* (2024) suggest that riboflavin pretreatment ameliorates salinity stress in rice.

Despite the abundant information about the benefits of chemical gibberellic acid and some chemical vitamins in improving plant growth, most of these studies were conducted on the individual use of each compound on crops other than onions. To the best of our knowledge, the effect of microbial gibberellic acid, microbial vitamins, or the interactions on onion yield or calcareous or sandy soil fertility has not been investigated in previous studies. Therefore, the current study was conducted to investigate the effect of spraying the microbial gibberellic acid and different vitamins (vitamin C, B1, and B2) produced microbially and industrially, as well as how the two factors interact on the following: 1) productivity of onion, 2) water productivity 3) fertility of calcareous sandy soil after crop harvesting.

MATERIALS AND METHODS

1. The preparation of microbial treatments

1.1 Microbial gibberellic acid (GA_3)

The endophytic fungus *Fusarium incarnatum* (ASU19) was separated from the roots of onions and cultured on potato dextrose agar (PDA) medium. Genetic identification was performed using primers ITS4 and ITS1, and the strain was registered in the National Centre for Biotechnology Information (NCBI) under the accession MK387876. For gibberellic acid (GA_3) production, *F. incarnatum* (MK387876) was incubated in PDA medium for five days, and conidia were harvested (Mahmoud *et al.*, 2021). A mineral broth medium with 2% triton X-conidia solution cultured for seven days at 28 ± 1 °C. (Mohamed & Mahmoud, 2018). After incubation, the fungal broth was collected, centrifuged, and extracted. According to Mohamed and Mahmoud (2018), the concentration was determined using the GA_3 standard curve, and the absorbance was determined at 254 nm.

1.2 Microbial Vitamins

1.2.1 Microbial ascorbic acid vitamin

Saccharomyces cerevisiae (ASU211) was grown for 24 hours at 30 ± 1 °C in yeast malt extract medium. To produce ascorbic acid, 2% of the inoculum was added to modified yeast-peptone medium (Banjo *et al.*, 2020). The medium was incubated for three days (72 hours) at 30 ± 1 °C. Following incubation, the fungus broth was collected and centrifuged (Nowosad *et al.*, 2022). To determine ascorbic acid, 515 nm was used to measure the absorbance, and the concentration was computed using the standard curve of ascorbic acid (Guimarães *et al.*, 2009).

1.2.2 Microbial riboflavin vitamin

On nutritional agar media, Bacillus subtilis (KU559875) was isolated from seeds of Egyptian clover, recognized genetically by sequencing the 16S rRNA gene, and deposited with accession number KU559875 at the National Centre of Biotechnology Information (NCBI). For the synthesis of riboflavin, Bacillus subtilis (KU559875) was cultivated in nutritional broth medium for 24 hours at 30 ± 1 °C (You *et al.* 2021). Following that, 2% of the inoculum was added to new medium, and it was incubated for three days (72 hours) at 30 ± 1 °C. The broth was gathered after incubation, centrifuged, combined with 1 M NaOH, and centrifuged once more to take out the bacterial cells (Mahmoud & Bashandy, 2021). To determine riboflavin, 444 nm was used to measure the absorbance, and the concentration was computed using the standard curve of riboflavin (Nafady *et al.*, 2015).

2. Experimental site

Two experiments in successive winter seasons, 2021-2022 and 2022-2023, were farmed in the testing farm of the Arab Al-Awammer Research Station, Agricultural Research Centre (ARC), Asyut, Egypt. Trials were conducted to test the treatments on onion (*Allium cepa* L., cv. Giza-6) productivity, protein yield and NPK, irrigation water use efficiency (IWUE) and water use efficiency (WUE) for dry and fresh bulb yield of onion, NPK availability and other soil characteristics at the end of the season. The experimental farm is located at the junction of latitudes 27°, 03° N and longitudes 31°, 01° E, and it is 71 meters above sea level. Table 1 shows the experimental site's climate data for the two growing seasons. The soil type was sandy calcareous, and the soil taxonomy classed it as a Typic Torripsamment (Soil Survey Staff, 2014). Table 2 shows some physical-chemical properties of the studied soil (0-0.25 m). The test site was irrigated using a stable sprinkler irrigation system with a square spacing pattern (12 m × 12 m). The rotating sprinklers were 1.0 meters above ground and had a flow rate of 1.2 to 1.4 m^3 per hour at 2 to 3 bars.

Table 1: Average monthly weather information for the Asyut weather station across the two farming seasons of 2021-2022 and 2022-2023

Parameter Month	Temperature (ċ)		Relative humidity %	Wind speed km/h	Sunshine hours
	Max	Min			
2021-2022					
December	20.3	7.7	54.7	10.7	9.0
January	17.1	4.5	57.1	10.3	8.9
February	20.2	6.4	51.0	13.8	9.7
March	22.6	8.4	39.2	18.0	9.9
April	34.6	16.2	26.4	15.4	10.3
2022-2023					
December	22.9	9.3	57.6	9.6	9.0
January	21.1	7.1	56.0	10.1	8.9
February	20.2	6.1	51.0	11.8	9.7
March	27.1	12.1	34.3	9.9	9.9
April	31.5	15.1	25.5	14.2	10.3

Table 2: Some physical-chemical characteristics of the soil (0-0.25 m) under study

Property	Unit	Value
Sand	(g kg^{-1})	876.7
Silt	(g kg^{-1})	80.6
Clay	(g kg^{-1})	42.7
Texture grade		Sand
Water holding capacity (WHC)	(g kg^{-1})	230.8
Bulk density	(ton m^{-3})	1.65
Organic matter	(g kg^{-1})	7.84
$CaCO_3$	(g kg^{-1})	280.5
pH $_{(1:1)}$		8.46
EC $_{(1:1)}$	(ds m^{-1})	0.58
Soluble cations (mmol kg^{-1})		
Calcium		1.67
Magnesium		0.69
Sodium		0.83
Potassium		0.26
Soluble anions (mmol kg^{-1})		
Bicarbonate		0.43
Chloride		1.54
Sulfate		1.92
Available macronutrients (mg kg^{-1})		
Nitrogen		32.2
Phosphorus (Olsen)		7.9
Potassium		40.1

The mean of three replicates is shown for each value.

3 Experimental Design

The current study used a split-plot design, with three replicates for each treatment. Two microbial gibberellic acid treatments (with or without GA_3) was put into the main plot at a rate of 150 mg l^{-1}, and six vitamin treatments (control (Ck), chemical thiamine (CT), microbial ascorbic acid (MA), chemical ascorbic acid (CA), microbial riboflavin (MR), and chemical riboflavin (CR) were put into the sub-plots at a rate of 100 mg l^{-1}. Consequently, all the plots of the experiment were 2 × 6 × 3 = 36 plots, each plot was 3m × 3.5m = 10.5 m^2 =1/400 feddan or 1/952.4 ha (feddan = 4200 m^2). The experimental field's soil was tilled twice perpendicularly and was settled, then divided into plots and prepared by hoeing to create seven ridges, each three metres long and fifty centimetres broad. The experimental plots were provided with a 3 m-wide buffer zone to protect them from outside influences. Preparation of microbial GA_3, ascorbic acid, and riboflavin as described before, while chemical ascorbic acid, chemical riboflavin, and chemical thiamine were purchased from Alfa Chemical, China. The treatments were applied using the foliar spray method. Every time, 500 mL of the treatment solution was sprayed on each plot. Plots were sprayed twice: initially 45 days after transplanting and again a month later (75 days after transplanting). The wetting agent Triton B was applied to all treatments throughout the spraying process, and onion plants were sprayed using a knapsack hand sprayer.

4 Crop evapotranspiration (ETc) and applied irrigation water

According to Allen *et al.* (1998), actual ETc was calculated using the formula ETc = ETo × Kc, where: Kc is the crop coefficient. Reference evapotranspiration (ETo) was computed using the CROPWAT model (version 8) in accordance with the Penman-Monteith equation (Allen *et al.*, 1998; Smith, 1991). The climate data in Table 1 was used to calculate the ETo values. In harmony with Allen *et al.* (1998), Kc was used for various stages of onion growth (first stage, developmental stage, mid-season stage, and late-season stage). In accordance with James (1988), we calculated the total actual irrigation water applied mm/interval (I. Ra) by the equation I. Ra = (ETc + Lf)/Er, where ETc = crop evapotranspiration, Lf = leaching factor, and Er = irrigation system efficiency. Depending on the monthly growth stage, ETc and irrigation water application fluctuated as described in Table 3. Readings were lowest in December, reached their highest value in March, and then dropped in April in the late-season stage in both seasons. As the seasonally average wind speed was 13.64 km/h in the first season and 11.12 km/h in the second season, it resulted in a larger total volume of ETc and irrigation water applied (536.79 mm and 7157.24 m^3 ha^{-1}, respectively) in the first season than in the second season (505.43mm and 6739.08 m^3 ha^{-1}, respectively).

Table 3. Crop evapotranspiration (ETc, mm) and irrigation water applied (m^3 ha^{-1}) at the monthly growth stage of onion during the seasons of 2021-2022 and 2022-2023.

Season	Season 1		Season 2	
Month	ETc mm	Applied irrigation water (m^3 ha^{-1})	ETc mm	Applied irrigation water (m^3 ha^{-1})
December	51.45	686.00	45.96	612.82
January	86.61	1154.78	98.94	1319.23
February	122.41	1632.11	116.43	1552.44
March	176.22	2349.56	148.02	1973.55
April	100.11	1334.78	96.08	1281.05
Total	536.79	7157.24	505.43	6739.08

5 Estimation of water productivity

5.1 Water use efficiency (WUE) and irrigation water use efficiency (IWUE) for onion fresh or dry bulb yield

In line with Zahran (2025), water use efficiency for onion fresh or dry bulb yield (fresh or dry-WUE) was calculated using the equation {onion fresh or dry bulb yield (kg ha^{-1})/ETc (mm)}. Irrigation water use efficiency for onion fresh or dry bulb yield (fresh or dry -IWUE) was calculated as follows: equation {onion fresh or dry bulb yield (kg ha^{-1})/ applied irrigation water (m^3 ha^{-1})}.

6 Conditions for plant growth

Onion seedlings, sixty-five days old, were transplanted 7 cm apart on either side of each ridge (each plot has about 300 seedlings). In both seasons, the strong and homogeneous seedlings were selected and transplanted in the first 7 days of December. During the soil preparation and before seedlings cultivation, in one dose, P was added at the rate of 107.14 kg P_2O_5/ha as granular superphosphate (15% P_2O_5). N fertilizer was applied as ammonium nitrate (33.5% N) at the rate of 285.7 kg N/ha divided into seven identical doses every twelve days (starting 20 days after transplanting). Potassium sulfate fertilizer (50% K_2O) was chosen as a supply of K at the level of 119 kg K_2O/ha, divided into four equal doses (after 45, 65, 75, and 85 days from transplanting). Chelated Mn, Fe, and Zn in a liquid mixture containing Tritona B, as a wetting agent, and 150 ppm of each were applied twice as a foliar spray at a rate of 476.2 L/ha each. The previous and other agriculture practices were conducted in agreement with the onion extension guide, Ministry of Agriculture, Egypt.

7 Estimation of onion production

Marketable onions were harvested per Egyptian Ministry of Agriculture guidelines. Onion shoots were removed, and fresh weight was determined by individually weighing bulbs per plot, with results converted to total bulb yield (ton ha^{-1}). Ten bulbs were chosen at random from each plot, and the samples were transported directly to the laboratory. Samples of bulbs were cleaned, weighed, and cut. For three days, the sliced samples were spread out on the laboratory benches to lessen the moisture content. Following that, bulb samples were dried for three days at 70 °C, or until their weight didn't change, at which point they were weighed. In accordance with Zahran (2025), the dry matter percent and dry onion bulb yield were calculated using the following formulas: Dry matter (%) = {(Dry weight (g)/ Fresh weight (g)} × 100. Onion dry bulb yield ton ha^{-1} = {(Dry mater (%) × Fresh onion bulb yield (ton ha^{-1})/100}.

8 Plant analysis

To determine the total P, K, and N in onion ground dried samples, 0.50 g of each sample was digested with 15 ml of digestion mixture (350 ml H_2O_2 + 0.42 g selenium powder + 14 g $LiSO_4.H_2O$ + 420 ml of concentrated H_2SO_4 was added carefully with cooling) (Parkinson & Allen, 1975). Total phosphorus was measured colorimetrically by the stannous chloride phosphomolybdic-sulfuric acid method as described by Jackson (1973). N determination was carried out using the micro-Kjeldahl procedure (Jackson, 1973), and total potassium was measured by the flame photometric method (Page, 1982). The protein content is calculated by multiplying the nitrogen content by 6.25 (Zahran *et al.,* 2020). In line with Zahran (2025), NPK uptakes (kg ha^{-1}) and protein yield (kg ha^{-1}) were calculated as follows equations N or P or K uptakes (kg ha^{-1}) or protein yield (kg ha^{-1}) = bulbs dry yield (ton ha^{-1}) × N or P or K or protein (%) ×10.

9 Soil analysis

A composite soil sample (0-0.25 m) was collected from the empirical site before the onion plants were transplanted. Likewise, composite soil samples were collected from each plot unit at the end of each season, but at a depth of 0-0.20 m. Soil samples were collected by an auger, airdried, and crushed to pass through a 2-mm sieve. In agreement with Klute (1986) and Jackson (1973), certain chemical and physical characteristics of the studied soil were determined. The soil pH was determined in a 1:1 soil-to-water suspension using a digital pH meter with a glass electrode (Jackson, 1973). The mixtures were filtered, and the extracts were used to measure electrical conductivity using an electrical conductivity meter (Baruah & Barthakur, 1997). Soil organic matter content was measured by the Walkley–Black wet oxidation method as described by Jackson (1973). Available soil nitrogen was extracted, and by using a micro-Kjeldahl distillation apparatus and Devarda's alloy, the extract was distilled, and available nitrogen (nitrate and ammonium) was measured (Page, 1982). In line with Olsen *et al.* (1954), which is the recommended method for high pH soils, available soil phosphorus (Olsen-P) was extracted by 0.5 M $NaHCO_3$ (pH 8.5), and P was estimated colorimetrically using the chlorostannous phosphomolybdic acid procedure, in accordance with Jackson (1973). A flame photometer was used to determine the available K following its extraction with 1 M ammonium acetate at 7.0 pH (Baruah & Barthakur, 1997).

10 Statistical analysis

A split-plot design including three replicates was used to test the treatments. Two-way analysis of variance (ANOVA) was used to determine if the differences between the treatments were significant. At the 5% level of probability, the means were compared using Duncan's multiple range tests. Data are tabulated as the means ± standard error (SE). IBM SPSS Statistics version 25 was used to conduct standard error (SE), Duncan's multiple range test, and data statistical analysis.

RESULTS

1 Onion productivity

1.1 Total fresh and dry bulb yield

Information about onion total fresh and dry bulb yield (ton ha^{-1}) and dry matter content at maturity under microbial gibberellic acid, vitamin treatments, and their interaction is illustrated in Figure 1 and Table 4. Results indicated that microbial gibberellic acid spraying highly significantly ($P < 0.01$) enhanced total fresh and dry bulb yields in both seasons, while dry matter content improved only significantly ($P < 0.05$). Similarly, vitamin spray treatments highly significantly enhanced total fresh and dry bulb yields, while dry matter content improved significantly in the first season and highly significantly in the second season. On the other hand, interaction treatments significantly increased fresh and dry bulb yields over two seasons but had no significant impact on dry matter content. Microbial gibberellic acid (fungal gibberellic acid) foliar application produced the highest total fresh and dry bulb yield across both seasons, outperforming the untreated control, which produced the lowest. This represented yield increases of 21.61–25.73% (fresh) and 30.61–34.90% (dry) during both study seasons, respectively, compared to the control. Additionally, the average dry matter content for the two seasons changed from 12.09% in the control treatment to 12.98% in the microbial gibberellic acid treatment, an increase of 7.33% as compared with the control. In relation to the sub-effect, microbial ascorbic acid vitamin (fungal ascorbic acid) showed the highest effect on total fresh yield (30.02 and 33.17 tons per hectare) and total dry bulb yield (3.940 and 4.214 tons per hectare), significantly outperforming other vitamin treatments in both seasons, respectively. Microbial riboflavin (bacterial riboflavin) treatment was the second influence, producing 28.95 and 31.81 tons per hectare in fresh bulb yield and 3.760 and 4.004 tons per hectare in dry bulb yield in the two seasons, respectively. Chemical thiamine treatment was in the third effect. This enhanced effect was followed by the influence of ascorbic and riboflavin vitamins from chemical sources, without significant differences between them, but with significant differences between them and the control treatment. Additionally, in comparison to the control, the treatment of microbial ascorbic acid increased total fresh bulb yield by 22.81, and 24.78% and increased total dry bulb yield by 31.97 and 33.97% in seasons one and two, respectively, whereas the treatment of microbial riboflavin enhanced total fresh bulb yield by 18.45 and 19.66 % and enhanced total dry bulb yield by 25.97 and 27.28% in seasons one and two, respectively. Additionally, the average dry matter content for the two seasons changed from 11.99% in the control treatment to 12.86% in the microbial ascorbic acid treatment, an increase of 7.29% as compared to the control. Data of the interaction revealed that combined microbial gibberellic acid (GA_3) and microbial ascorbic acid foliar applications achieved the highest total fresh yield and dry bulb yields (4.501-4.847 tons per hectare) for both seasons, respectively. It significantly suppressed that of the other 11 treatments. Microbial gibberellic acid with microbial riboflavin was in the second order, with no significant differences between it and the gibberellic acid plus chemical thiamine treatment, which came in the third rank. Both treatments of gibberellic acid plus chemical ascorbic or chemical riboflavin followed the abovementioned effect. There are positive, statistically significant changes between each interaction treatment and the control treatment, which came in the last rank, which was 2.654 and 2.714 tons per hectare for dry bulb yield in seasons one and two, respectively. Furthermore, as compared with the control, the treatment of gibberellic acid plus microbial ascorbic acid increased total dry bulb yield by 69.55% and 78.61% in seasons one and two, respectively.

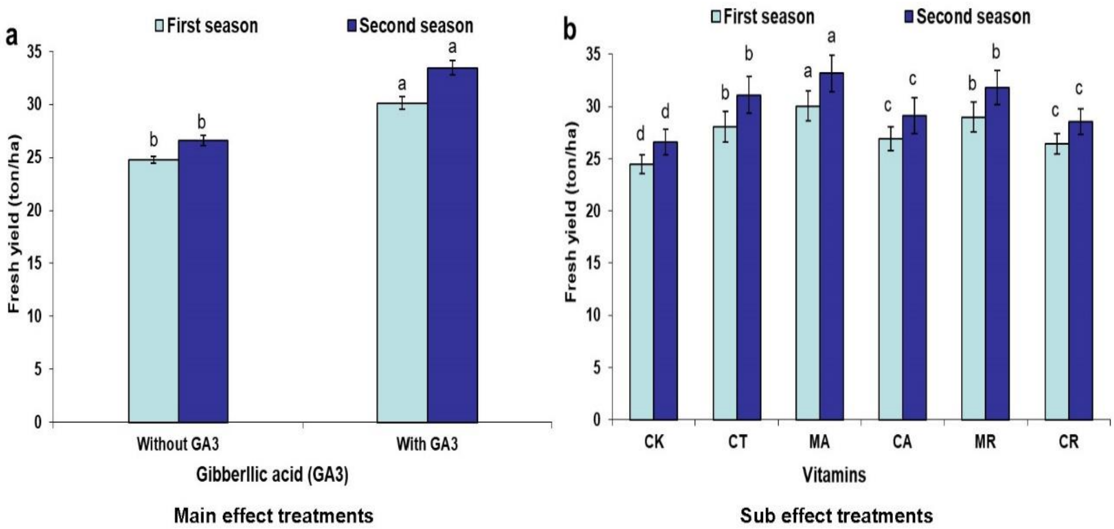

Figure 1. Total fresh bulb yields, as influenced by microbial gibberellic acid (a) and vitamins (b) at the end of two seasons. Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data is displayed as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the *P* < 0.05 level.

Table 4: Total dry bulb yield (ton ha^{-1}) and dry matter content (%) as influenced by microbial gibberellic acid (GA_3), vitamins, and their interactions at the end of the season.

Parameters		**Total dry bulb yield (ton ha^{-1})**		**Dry matter (%)**	
Treatments		**Season 1**	**Season 2**	**Season 1**	**Season 2**
GA_3 (A)					
Without GA_3		3.048±0.06b	3.173±0.07b	12.29±0.10b	11.90±0.09b
With GA_3		3.981±0.10a	4.280±0.10a	13.19±0.11a	12.77±0.08a
Vitamins (B)					
CK		2.985±0.15e	3.146±0.20e	12.19±0.27b	11.79±0.20c
CT		3.608±0.25c	3.873±0.27c	12.82±0.27a	12.40±0.21ab
MA		3.940±0.26a	4.214±0.29a	13.07±0.27a	12.65±0.23a
CA		3.446±0.19d	3.623±0.27d	12.78±0.21a	12.39±0.19ab
MR		3.760±0.24b	4.004±0.27b	12.94±0.24a	12.54±0.22a
CR		3.348±0.19d	3.498±0.22d	12.63±0.26 ab	12.21±0.27b
GA_3 × Vitamins (A × B)					
Without GA_3	CK	2.654±0.03g	2.714±0.02h	11.76±0.17d	11.38±0.07d
	CT	3.072±0.08ef	3.265±0.08f	12.39±0.32cd	12.00±0.16bc
	MA	3.379±0.08d	3.582±0.10e	12.57±0.29bc	12.19±0.21b
	CA	3.021±0.03f	3.038±0.08g	12.38±0.18cd	12.00±0.15bc
	MR	3.231±0.02de	3.419±0.06ef	12.53±0.16bc	12.15±0.17b
	CR	2.932±0.10f	3.019±0.07g	12.08±0.20cd	11.68±0.23cd
With GA_3	CK	3.316±0.05d	3.578±0.09e	12.62±0.40bc	12.20±0.13b
	CT	4.145±0.10b	4.481±0.04b	13.25±0.26ab	12.80±0.19a
	MA	4.501±0.07a	4.847±0.09a	13.57±0.13a	13.11±0.03a
	CA	3.871±0.03c	4.209±0.06c	13.18±0.19ab	12.79±0.04a
	MR	4.290±0.09b	4.589±0.08b	13.36±0.32a	12.94±0.25a
	CR	3.764±0.08c	3.978±0.07d	13.18±0.06ab	12.75±0.11a
P: A		**	**	*	*
P: B		**	**	*	**
P: A × B		*	*	ns	ns

GA_3; microbial gibberellic acid, Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the $P < 0.05$ level. As a result of a two-way ANOVA, ns = non-significant; * $P < 0.05$; ** $P < 0.01$.

1.2 Macronutrient uptakes (kg ha^{-1})

Generally, NPK uptake and protein yield per hectare was in the same trend as the previously described onion bulb dry yield. Data regarding NPK uptake and protein yield under two microbial gibberellic acid treatments, vitamins, and their interaction were illustrated in Table 5 and Figure 2. In both study seasons, statistical analysis proved that gibberellic acid (main plot) and vitamin treatments (subplot) highly significantly enhanced ($P < 0.01$) NPK uptake and protein yield. The interaction between gibberellic acid and vitamin treatments significantly promoted ($P < 0.05$) NPK uptake in both seasons, except for two cases in nitrogen uptake and protein yield in the second season, where the interaction showed a highly significant effect ($P < 0.01$). Microbial gibberellic acid foliar application yielded the greatest NPK uptake and protein yield per hectare across both seasons. As compared with the control, the improvement caused by microbial gibberellic acid treatment was 41.5 and 45.5% for N, 46.0 and 52.9% for P, and 41.5 and 46.0% for K during the two seasons, respectively. In terms of the effect of the subplot vitamin treatments, foliar application of microbial ascorbic acid resulted in the highest NPK and protein yields (106.2-14.3 - 94.0 - 663.9 kg per hectare in the first season and 116.6-16.2 - 103.7 - 729.0 kg per hectare in the second season). Furthermore, microbial vitamin C outperforms other vitamin treatments on P uptake in both seasons. Microbial riboflavin treatment was evaluated in the second order, producing 103.1 - 13.2 - 90.1 - 644.2 kg NPK and protein yield per hectare during the first season and 114.2 - 15.1 - 99.1 - 713.7 kg NPK and protein yield per hectare during the second season, respectively, with no significant differences between it and the treatment with microbial ascorbic acid on NK and protein yield per hectare. Chemical thiamine treatment came in third place, which was significantly higher than the other treatments list. Ascorbic or riboflavin vitamins from chemical sources showed a lower influence, with insignificant differences between them, and with significant differences as compared to CK treatment. Additionally, in comparison with the control, the microbial ascorbic acid foliar application boosted NPK yield by 41.2 - 42.9 - 41.7% and 39.0 - 48.9 - 42.5% in each of the two seasons, respectively, while the microbial riboflavin treatment raised NPK yield by 37.0 - 32.7 – 35.7 and 36.1 - 38.5 – 36.2 % in each of the two seasons, respectively. The interaction demonstrated that foliar applications of microbial GA_3 and microbial vitamin C induced the largest amount of NPK uptake and protein yield, which are 125.6 - 16.4 - 110.8 – 784.9 and 137.4 - 18.7 - 123.7 - 858.8 kg per hectare in 2021/2022 and 2022/2023, respectively. Additionally, compared to the other interaction treatments, it is significantly superior in most cases. GA_3 with microbial vitamin B2 followed in order GA_3 and C with 120.8 - 15.7 - 106.1 - 755.2 and 134.4 - 17.8 - 117.7 - 840.2 kg NPK and protein yield per hectare in the two seasons, respectively. GA_3 with vitamin B1 treatment came in the third position. Treatments of gibberellic acid plus chemical ascorbic or chemical riboflavin showed a lower effect. In the first season, no significant differences were observed between them; however, in the second season, significant differences were detected. The majority of interaction treatments have significant differences between them and the control.

Table 5: NPK uptakes (kg ha^{-1}) as influenced by microbial gibberellic acid (GA_3), vitamins, and their interactions at the end of the season.

Parameters		Nitrogen uptake (kg ha^{-1})		Phosphorus uptake (kg ha^{-1})		Potassium uptake (kg ha^{-1})	
Treatments		**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
GA_3 (A)							
Without GA_3		77.3±2.03b	83.8±2.35b	10.02±0.31b	10.99±0.44b	67.0±1.83b	71.8±2.19b
With GA_3		109.5±3.21a	122.0±3.42a	14.63±0.42a	16.80±0.49a	94.7±2.95a	104.9±3.34a
Vitamins (B)							
CK		75.2±5.37d	83.9±6.39d	9.99±0.69d	10.87±1.03d	66.4±4.37d	72.8±4.93d
CT		97.1±8.23b	108.2±9.75b	12.87±1.19b	14.74±1.32b	82.5±6.15b	90.1±7.00b
MA		106.2±8.72a	116.6±9.45a	14.27±0.99a	16.19±1.12a	94.0±7.65a	103.7±9.19a
CA		91.2±6.71c	99.2±9.37c	11.93±1.21c	13.68±1.76c	76.4±6.12c	83.3±8.08c
MR		103.1±8.13a	114.2±9.09a	13.25±1.13b	15.06±1.28b	90.1±7.28a	99.1±8.61a
CR		87.5±6.69c	95.3±7.79c	11.63±1.16c	12.84±1.49c	75.7±6.71c	81.2±7.61c
GA_3 × Vitamins (A × B)							
Without GA_3	CK	63.3±1.14f	69.9±0.90h	8.53±0.20g	8.62±0.20e	57.0±2.58g	62.0±2.19e
	CT	79.2±2.60e	86.5±0.82f	10.26±0.20ef	11.85±0.28d	68.9±1.46ef	74.7±2.12d
	MA	86.9±0.54d	95.9±2.35e	12.12±0.35d	13.74±0.21c	77.3±0.49d	83.7±2.14c
	CA	76.5±0.90e	78.5±2.40g	9.29±0.30fg	9.83±0.32e	63.4±1.43fg	65.5±2.07e
	MR	85.3±2.38d	94.0±1.47e	10.81±0.32e	12.32±0.26cd	74.1±2.25de	80.5±3.13cd
	CR	72.8±2.87e	78.3±3.53g	9.10±0.25fg	9.60±0.09e	61.2±1.45g	64.5±2.92e
With GA_3	CK	87.2±1.17d	97.9±2.66e	11.45±0.47de	13.13±0.46cd	75.8±0.68d	83.5±1.02c
	CT	115.1±2.87b	129.9±1.92b	15.48±0.44ab	17.62±0.50a	96.1±0.97b	105.4±2.27b
	MA	125.6±2.15a	137.4±3.07a	16.42±0.33a	18.65±0.49a	110.8±3.29a	123.7±4.35a
	CA	105.9±2.87c	119.9±2.02c	14.57±0.44bc	17.53±0.72a	89.4±3.96c	101.0±2.48b
	MR	120.8±3.10ab	134.4±1.14ab	15.69±0.58ab	17.80±0.75a	106.1±2.1a	117.7±3.76a
	CR	102.1±0.98c	112.3±1.63d	14.15±0.53c	16.07±0.74b	90.2±2.63bc	97.8±1.89b
P: A		**	**	**	**	**	**
P: B		**	**	**	**	**	**
P: A × B		*	**	*	*	*	*

GA_3; microbial gibberellic acid, Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the $P < 0.05$ level. As a result of a two-way ANOVA, ns = non-significant; * $P < 0.05$; ** $P < 0.01$.

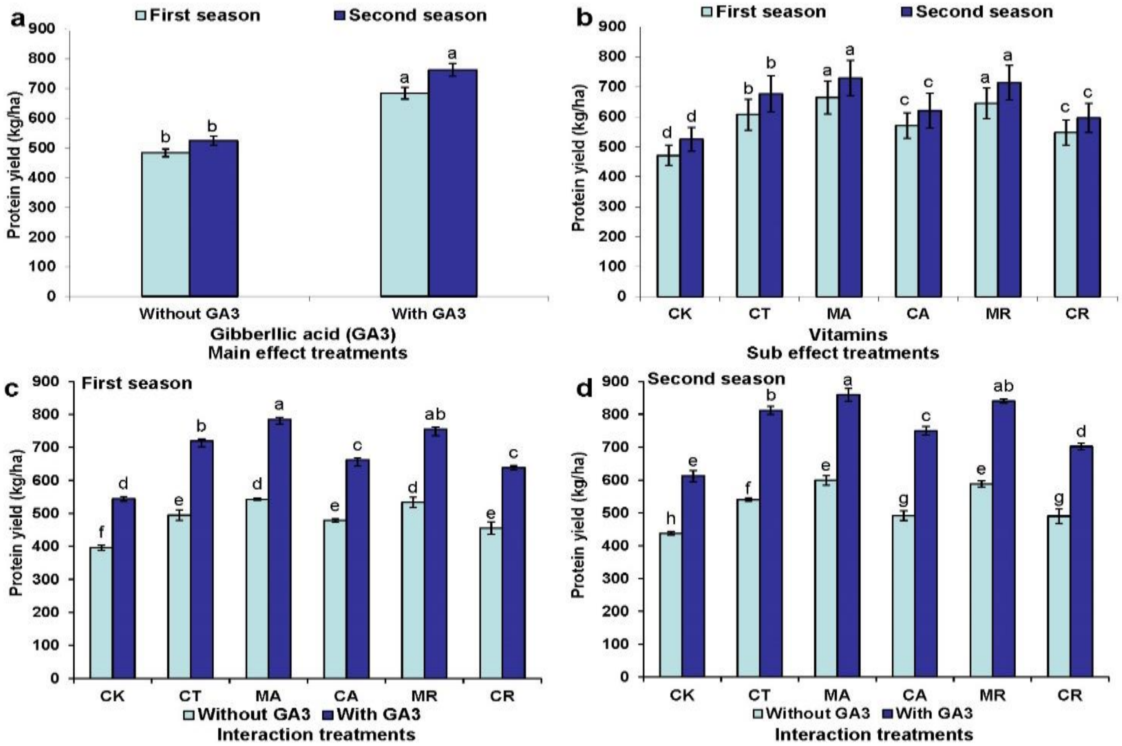

Figure 2. Protein yield as influenced by microbial gibberellic acid (a) and vitamins (b), as well as their interaction (c and d) at the end of two seasons. Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the $P < 0.05$ level.

3 Water productivity

WUE and IWUE for total fresh and dry bulb yield as influenced by microbial gibberellic acid and different vitamins and their interactions are clarified in Figures 3, 4, and Table 6. Spraying microbial gibberellic acid highly significantly ($P < 0.01$) improved WUE and IWUE of fresh and dry bulb yield in both seasons. Similarly, vitamin treatments had a highly significant positive effect. Their interaction also significantly enhanced WUE and IWUE during both seasons. Microbial gibberellic acid foliar application produced the greatest WUE and IWUE for onion fresh and dry bulb yield. Compared to the control, microbial GA_3 acid augmented WUE in fresh bulb yield by 21.6 and 25.7% and by 30.6 and 34.9% for WUE in dry bulb yield in the first and second seasons, respectively. Regarding the sub-effect result, the greatest WUE and IWUE for onion fresh and dry bulb yield was recorded with microbial ascorbic acid. Compared to the control, microbial ascorbic acid treatment in the first and second seasons improved WUE in fresh bulb yield by 22.8 and 24.8% respectively, and by 32.0 and 34.0% for WUE in dry bulb yield. On the other hand, microbial riboflavin boosted WUE in fresh bulb yield by 18.4 and 19.7% and by 26.0 and 27.3% for WUE in dry bulb yield in both seasons, respectively, as compared to the control. Data on how two factors interact show that the highest WUE and IWUE for onion fresh bulb yield were found in the interaction treatment of the biological GA_3 and biological ascorbic acid giving 61.8 & 46.3 (1st season) and 73.1 & 54.8 kg mm^{-1} (2nd season), followed by the interaction of microbial GA_3 with biological riboflavin 59.8 & 44.9 kg mm^{-1} (1^{st} season) and 70.2 &52.7 kg mm^{-1} (2^{nd} season). microbial GA_3 and chemical thiamine came in the third place, while microbial GA_3 with chemical ascorbic acid or chemical riboflavin came in fourth and fifth ranks. On the other hand, WUE and IWUE for onion dry bulb yield were in the same trend.

Table 6: Irrigation water use efficiency for fresh and dry bulb onion yield as influenced by gibberellic acid (GA_3), vitamins, and their interactions at the end of the season.

Parameters		Fresh - IWUE (kg mm^{-1})		Dry - IWUE (kg mm^{-1})	
Treatments		**Season 1**	**Season 2**	**Season 1**	**Season 2**
GA_3 (A)					
Without GA_3		34.63±0.48b	39.51±0.70b	4.26±0.08b	4.71±0.11b
With GA_3		42.11±0.82a	49.68±0.98a	5.56±0.14a	6.35±0.15a
Vitamins (B)					
CK		34.15±1.23d	39.45±1.85d	4.17±0.21e	4.67±0.29e
CT		39.18±2.08b	46.16±2.63b	5.04±0.35c	5.75±0.41c
MA		41.95±2.00a	49.22±2.59a	5.50±0.36a	6.25±0.43a
CA		37.58±1.59c	43.20±2.56c	4.81±0.27d	5.38±0.39d
MR		40.45±1.99b	47.20±2.48b	5.25±0.34b	5.94±0.39b
CR		36.89±1.41c	42.34±1.82c	4.68±0.27d	5.19±0.32d
GA_3 × Vitamins (A × B)					
Without GA_3	CK	31.54±0.27g	35.40±0.38h	3.71±0.04g	4.03±0.02h
	CT	34.65±0.36ef	40.37±0.58f	4.29±0.11ef	4.84±0.11f
	MA	37.56±0.82d	43.59±0.99e	4.72±0.11d	5.31±0.14e
	CA	34.08±0.15f	37.57±0.79g	4.22±0.04f	4.51±0.12g
	MR	36.03±0.47de	41.75±0.54ef	4.51±0.03de	5.07±0.09ef
	CR	33.89±0.59f	38.39±0.85g	4.10±0.13f	4.48±0.10g
With GA_3	CK	36.76±0.80d	43.49±0.76e	4.63±0.07d	5.31±0.14e
	CT	43.71±1.01b	51.96±0.78b	5.79±0.14b	6.65±0.05b
	MA	46.33±0.41a	54.85±0.89a	6.29±0.09a	7.19±0.13a
	CA	41.07±0.59c	48.84±0.57c	5.41±0.04c	6.25±0.09c
	MR	44.88±0.20ab	52.65±0.79b	5.99±0.13b	6.81±0.12b
	CR	39.90±0.71c	46.29±0.48d	5.26±0.11c	5.90±0.10d
P: A		**	**	**	**
P: B		**	**	**	**
P: A × B		*	*	*	*

GA_3; microbial gibberellic acid, Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the $P < 0.05$ level. As a result of a two-way ANOVA, ns = non-significant; * $P < 0.05$; ** $P < 0.01$.

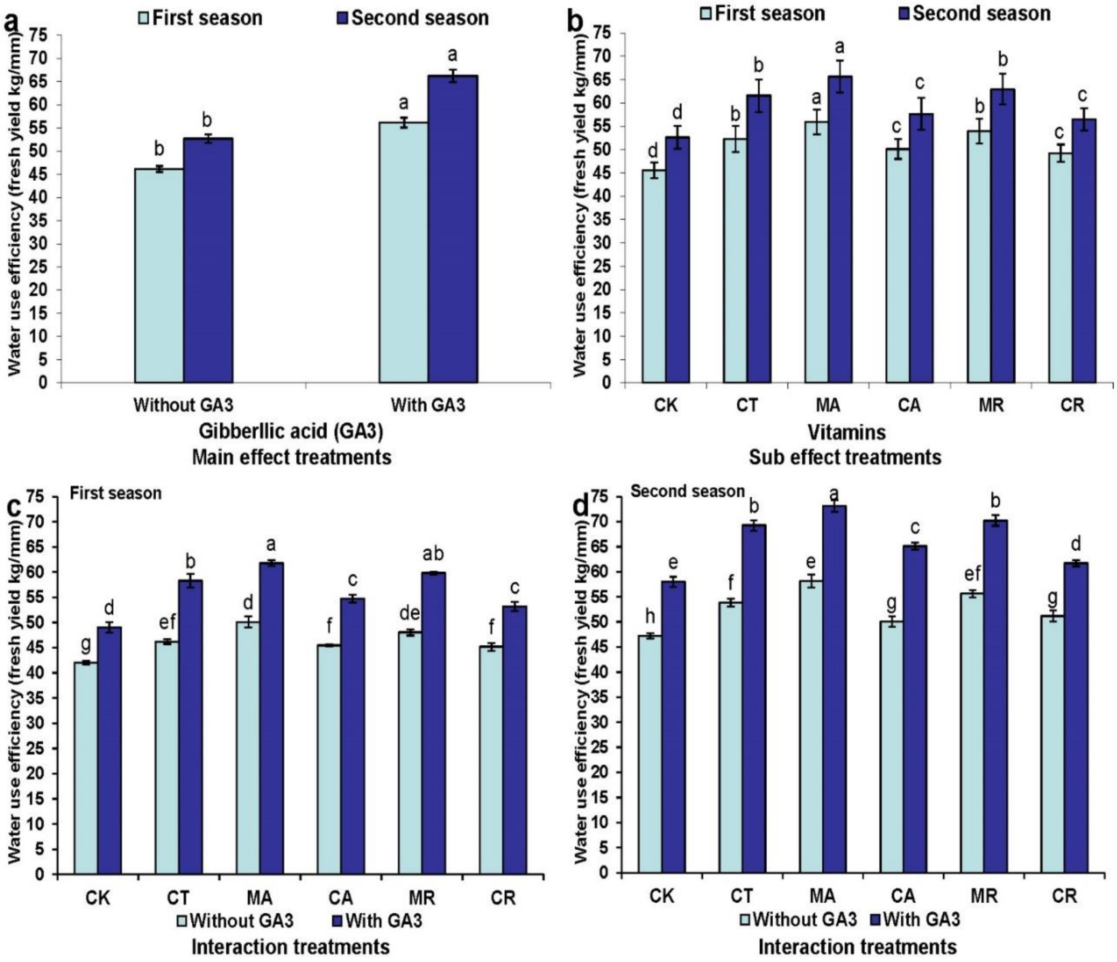

Figure 3. Water use efficiency for fresh bulb onion yield as influenced by microbial gibberellic acid (a) and vitamins (b), as well as their interaction (c and d) at the end of two seasons. Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the *P* < 0.05 level.

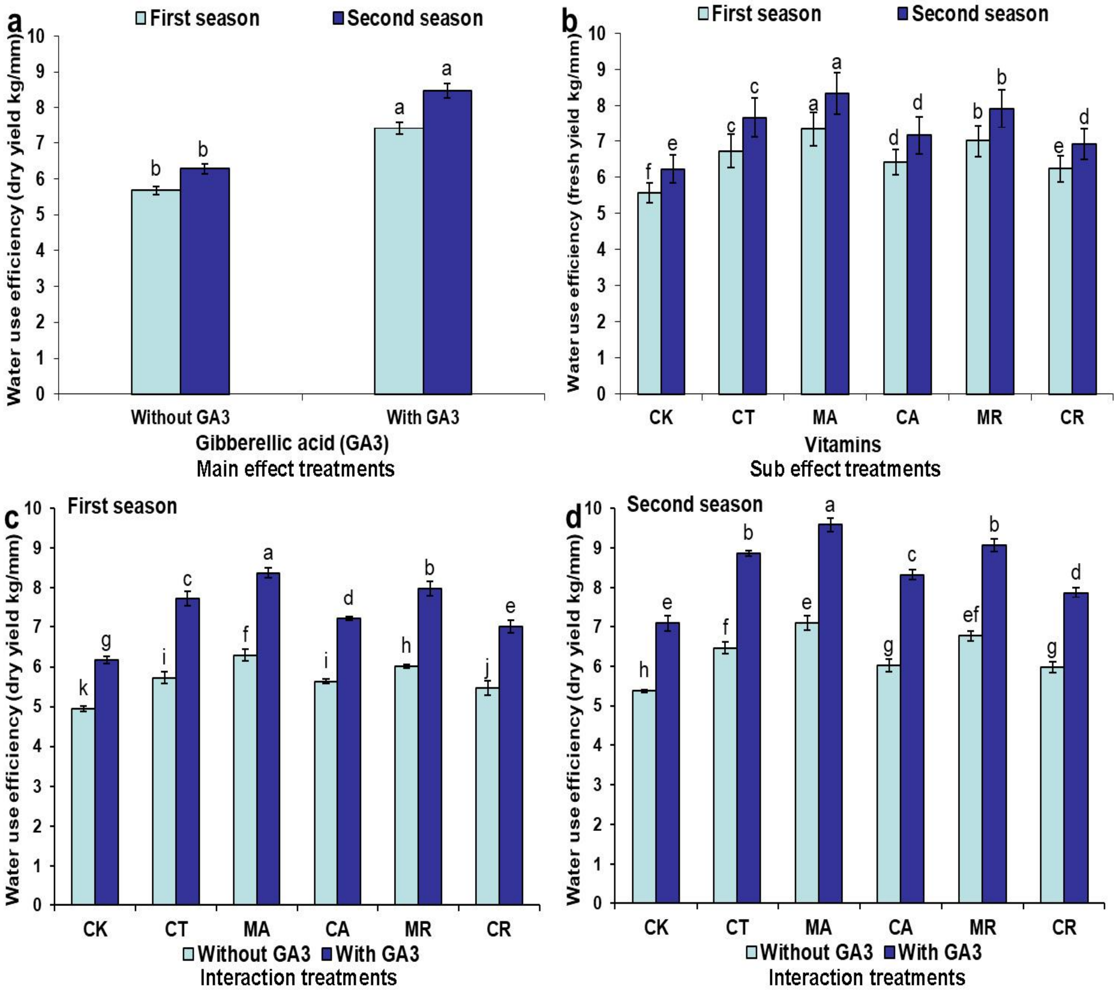

Figure 4. Water use efficiency for dry bulb onion yield as influenced by microbial gibberellic acid (a) and vitamins (b), as well as their interaction (c and d) at the end of two seasons. Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the *P* < 0.05 level.

4. Soil properties

4.1 Soil available NPK (mg kg^{-1})

In general, the experiment treatments affected the three available NPK differently. Details of data about available NPK under gibberellic acid, vitamins, and their interaction treatments are displayed in Table 7. During both study seasons, statistical analysis of available NPK findings indicated that microbial gibberellic acid attained a significant increment ($P < 0.05$) on only available NP; in contrast, vitamins treatments did not significantly ($P > 0.05$) affect the available soil NPK. On the other hand, interaction between microbial gibberellic acid and vitamin treatments in the first and subsequent seasons achieved just a significant enhancement ($P < 0.05$) in the soil available NP. In relation to interaction, the data indicate narrow differences between treatments, except for the difference between microbial gibberellic acid plus different vitamins and the control treatment. The chemical ascorbic acid plus microbial gibberellic acid achieved the highest amount of available N, followed by the effect of chemical riboflavin plus microbial gibberellic. On the other side, microbial GA_3 foliar application with chemical ascorbic acid or microbial riboflavin or chemical riboflavin or microbial ascorbic acid obtained the highest soil available P without significant differences between them, which was 10.8, 10.6, 10.3, and 10.2, respectively, in the first season and 10.0, 10.0, 9.6, and 9.4 in the second season, respectively. Whereas microbial GA_3 alone or chemical ascorbic acid alone achieved 9.5 and 8.8 soil available P at the same seasons. The microbial riboflavin treatment displayed the lowest values, 8.1 and 7.3 mg kg^{-1} soil available P in two seasons, respectively.

Table 7: Soil available NPK (mg kg^{-1}) as influenced by gibberellic acid (GA_3), vitamins, and their interactions at the end of the season

Parameters		**Soil Available N (mg kg^{-1})**		**Soil Available P (mg kg^{-1})**		**Soil Available K (mg kg^{-1})**	
Treatments		**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
GA_3 (A)							
Without GA_3		36.0±0.5b	33.6±0.5b	8.8±0.15b	8.0±0.16b	45.6±0.6a	42.5±0.5a
With GA_3		38.8±0.5a	36.3±0.6a	10.1±0.17a	9.4±0.18a	48.0±0.6a	45.5±0.6a
Vitamins (B)							
CK		36.4±1.4a	34.2±1.4a	9.1±0.31b	8.2±0.32b	45.6±1.4a	42.5±1.3a
CT		37.5±0.7a	34.6±0.9a	9.1±0.25ab	8.4±0.32ab	48.3±1.4a	44.7±1.1a
MA		37.8±0.8a	35.4±0.8a	9.8±0.24a	9.1±0.24a	45.7±1.0a	45.2±1.3a
CA		37.9±1.2a	35.7±1.4a	9.9±0.47a	9.1±0.50a	47.0±1.2a	43.4±1.0a
MR		37.6±0.9a	35.0±0.9a	9.4±0.57ab	8.6±0.62ab	47.9±1.2a	44.7±1.3a
CR		37.3±1.4a	34.7±1.2a	9.6±0.41ab	8.9±0.39ab	46.3±1.1a	43.3±1.1a
GA_3 × Vitamins (A × B)							
Without GA_3	CK	33.5±0.7d	31.4±0.4e	8.6±0.39de	7.6±0.26de	43.6±1.0b	40.9±1.9c
	CT	36.5±1.1bcd	33.5±0.8bcde	8.9±0.31de	8.0±0.39cde	46.9±2.2ab	43.7±1.1abc
	MA	38.6±1.2ab	35.9±1.3abcd	9.5±0.28bcd	8.8±0.30bc	44.4±1.5ab	43.3±1.2abc
	CA	35.7±0.8bcd	33.1±0.7cde	8.9±0.42de	8.1±0.46cde	45.7±1.6ab	42.1±1.0bc
	MR	37.4±1.5abc	35.3±1.7abcde	8.1±0.20e	7.3±0.24e	46.9±1.8ab	43.2±1.7abc
	CR	34.4±0.9cd	32.3±1.0de	8.8±0.33de	8.2±0.25cde	46.0±1.4ab	41.5±1.1bc
With GA_3	CK	39.2±1.1ab	37.0±1.5abc	9.5±0.35cd	8.8±0.30bc	47.7±2.2ab	44.1±1.3abc
	CT	38.4±0.8ab	35.6±1.5abcd	9.4±0.39cd	8.7±0.49bcd	49.7±1.8a	45.8±2.0ab
	MA	37.1±1.0abc	35.0±1.2abcde	10.2±0.34abc	9.4±0.37ab	47.0±1.2ab	47.1±2.0a
	CA	40.0±1.4a	38.3±1.7a	10.8±0.33a	10.0±0.29a	48.4±1.7ab	44.6±1.6abc
	MR	37.9±1.5abc	34.8±1.1abcde	10.6±0.24ab	10.0±0.25a	48.9±1.6ab	46.1±1.8ab
	CR	40.1±1.0a	37.2±0.6ab	10.3±0.36abc	9.6±0.48ab	46.6±1.8ab	45.2±1.3abc
P: A		*	*	*	*	ns	ns
P: B		ns	ns	ns	ns	ns	ns
P: A × B		*	*	*	*	ns	ns

GA_3; microbial gibberellic acid, Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the $P < 0.05$ level. As a result of a two-way ANOVA, ns = non-significant; * $P < 0.05$; ** $P < 0.01$.

4.2 pH, EC, and OM

Information about pH, EC, and OM in the soil after harvesting as a result of gibberellic acid, vitamins, and their interactions is clarified in Table 8. During both study seasons, statistical analysis results proved that the effect of gibberellic acid treatments, vitamin treatments, and their interaction achieved a non-significant effect on pH, EC, and OM (P > 0.05), except for the main effect of microbial gibberellic acid on EC; the statistical difference was significant (P < 0.05).

Table 8: Soil pH, EC (dS m^{-1}) and OM (g kg^{-1}) as influenced by gibberellic acid (GA_3), vitamins and their interactions at the end of the season.

Parameters		**pH (1:1)**		**EC (1:1) dSm^{-1}**		**OM (g kg^{-1})**	
Treatments		**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
GA_3 (A)							
Without GA_3		8.23±0.05a	8.27±0.04a	0.61±0.01b	0.58±0.01b	8.72±0.10a	8.21±0.10a
With GA_3		8.25±0.05a	8.29±0.04a	0.64±0.01a	0.61±0.01a	8.39±0.10a	7.76±0.11a
Vitamins (B)							
CK		8.28±0.09a	8.27±0.06ab	0.63±0.02ab	0.60±0.01ab	8.27±0.17b	7.69±0.16b
CT		8.27±.0.08a	8.32±0.07ab	0.65±0.02a	0.61±0.02ab	8.59±0.17ab	8.01±0.22ab
MA		8.30±0.11a	8.34±0.10a	0.61±0.02ab	0.59±0.01ab	8.27±0.20b	7.89±0.20ab
CA		8.22±0.10ab	8.29±0.10ab	0.59±0.02b	0.57±0.02b	8.46±0.18ab	7.86±0.23ab
MR		8.12±0.07b	8.19±0.06b	0.62±0.02ab	0.59±0.02ab	8.78±0.15ab	8.15±0.20ab
CR		8.23±0.08ab	8.27±0.07ab	0.66±0.01a	0.64±0.01a	8.95±0.14a	8.33±0.16a
GA_3 × Vitamins (A × B)							
Without GA_3	CK	8.33±0.12abc	8.31±0.12a	0.62±0.03abc	0.59±0.02abc	8.39±0.19ab	7.79±0.12abcd
	CT	8.18±0.11bcd	8.24±0.10a	0.63±0.02abc	0.60±0.02abc	8.64±0.31ab	7.97±0.35abcd
	MA	8.22±0.17abcd	8.29±0.16a	0.60±0.03abc	0.58±0.02bc	8.43±0.24ab	8.10±0.24abcd
	CA	8.18±0.15abcd	8.24±0.14a	0.57±0.03c	0.55±0.02c	8.72±0.27ab	8.28±0.21abc
	MR	8.14±0.11cd	8.17±0.11a	0.60±0.02bc	0.57±0.02bc	8.96±0.18ab	8.49±0.12ab
	CR	8.30±0.11abcd	8.34±0.11a	0.64±0.01abc	0.62±0.01abc	9.19±0.14a	8.61±0.12a
With GA_3	CK	8.23±0.16abcd	8.24±0.06a	0.64±0.03abc	0.60±0.02abc	8.14±0.31b	7.58a±0.32cd
	CT	8.35±0.10ab	8.39±0.10a	0.66±0.03ab	0.63±0.03ab	8.55±0.23ab	8.05±0.33abcd
	MA	8.38±0.15a	8.38±0.16a	0.63±0.02abc	0.60±0.02abc	8.11±0.34b	7.68±0.32bcd
	CA	8.26±0.14abcd	8.34±0.16a	0.60±0.02abc	0.58±0.02abc	8.20±0.17b	7.43±0.19d
	MR	8.11±0.12d	8.20±0.09a	0.65±0.03abc	0.61±0.03abc	8.60±0.20ab	7.80±0.27abcd
	CR	8.16±0.11bcd	8.21±0.10a	0.69±0.02a	0.66±0.02a	8.72±0.16ab	8.05±0.20abcd
P: A		ns	ns	*	*	ns	ns
P: B		ns	ns	ns	ns	ns	ns
P: A × B		ns	ns	ns	ns	ns	ns

GA_3; microbial gibberellic acid, Ck; control, CT; chemical thiamine (vitamin B1), MA; microbial ascorbic acid (vitamin C), CA; chemical ascorbic acid (vitamin C), MR; microbial riboflavin (vitamin B2), CR; chemical riboflavin (vitamin B2). Data are presented as means ± standard error (n = 2 in microbial gibberellic acid treatments, n = 6 in vitamins treatments, n = 3 in interaction treatments). Conforming to Duncan's multiple range tests, the different higher letters denote significant differences at the P < 0.05 level. As a result of a two-way ANOVA, ns = non-significant; * P < 0.05; ** P < 0.01.

DISCUSSION

1 Onion productivity

Egypt is one of the most arid regions of the globe, where nearly 86% of its total land is hyper-arid and 14% is arid (Omran & Negm, 2020). In a hyper-arid area known for its little to no precipitation and extreme heat, the experiment was conducted. As described in Table 1. Soil characterized by sandy texture (87.7% sand), low clay content (4.3%), and a decrease in organic matter content (0.78%). Previous properties led to high bulk density (1.65 tons/m^3) and low water-holding capacity (23.1%). Additionally, the soil has a high percentage of total calcium carbonate (28.5%) and a high alkaline pH (8.46 in a 1:1 soil water suspension). These aforementioned conditions, next to the pristine nature of the soil, are the most effective in restricting soil productivity. According to the critical levels of sufficiency and deficiency limits for available macro and micronutrients given by Lindsay & Norvell (1978) and Page *et al.* (1982), the experimental soils are low in nutrient content. Thus, we anticipate a poor transport of nutrients to plant roots and their absorption. As a result of previous information, wise management was followed in irrigation and fertilization with major and minor nutrients, in addition to tested microbial treatments, to raise the productivity of the sandy calcareous soil and maintain soil fertility. In the present study, the results indicated that the spray application of microbial gibberellic acid, vitamin treatments (C, B1 and B2 from microbial and chemical sources), and interaction between the two factors highly significantly or significantly improved onion productivity (total dry and fresh bulb yield, dry matter content, protein yield and NPK uptake) as compared with control in both seasons except in dry matter content; the interaction difference was insignificant. Information and literature on the benefits of adding microbial gibberellic acid to improve onion productivity, especially in sandy calcareous soils, are limited. In this respect, Sorour *et al.* (2025) indicated that treating onions cultivated in clay soil for seed production by foliar gibberellic acid or gibberellic acid + cytokinin (100 ppm three times) had enhanced seed yield and yield components as compared with the control. About other vegetable crops, Khan *et al.* (2006) reported that the heaviest weight of dry tomato plant (21.1 g $plant^{-1}$) and calculated NPK uptake came from 10^{-8} GA_3 foliar application, whereas the lowest weight (8.3 g plant-^{1}) and NPK uptake came from the control treatment. Also, Tsiakaras *et al.* (2014) indicated that lettuces cultivated in clay loam soil (containing 8.2% total calcium carbonate) had higher production as a result of foliar spray of gibberellic acid with a medium concentration (25 mg L^{-1}). Likewise, many researchers have demonstrated the same direction in other vegetables such as potato (Caliskan *et al.*, 2021) and lettuce (Le *et al.*, 2021). On the other side about field crop, Farad *et al.* (2025) declared that the combined application of organic manures along with gibberellic acid enhanced wheat yield (seed, straw, and biological yields) and wheat quality (protein or N in straw and seed) under a deep tillage system (once in five years) and should be used by farmers in order to produce a high-quality wheat yield. A similar trend on guava fruit trees was reported by Masood *et al.* (2025). These increases in onion productivity in our study, can be attributed to the different roles of gibberellic acid hormone in plants, such as modify the growth pattern of treated plants by enhancing DNA, RNA, protein synthesis, polyribosome, and ribose multiplication (Khan *et al.*, 2006); it also activates starch analyzing and IAA manufacture and stops the auxin breaking (Mukherji & Ghosh, 2005). Gibberellic acid increases and regulates cell division, hyperplasia, and elongation, and increases cell wall elasticity (Islam *et al.*, 2021; Thuc *et al.*, 2021). Also, gibberellic acid plays a part in stimulating metabolic activities, growth and development of chloroplasts; promoting the photosynthesis of representative pigments; and increasing the efficiency of representative photosynthesis (Pal *et al.*, 2016; Islam *et al.*, 2021) and also works to prevent the breakdown of chlorophyll and reduce reactive oxygen species levels that lead to the stimulation of cell death (El-Kamar *et al.*, 2013).

Concerning vitamins, there is a dearth of data and research on the advantages of using the different vitamins discussed in this article to increase onion yield, particularly in sandy calcareous soils. Concerning vitamin C, Abdel Hafeez & Ewees (2018) reported that ascorbic acid foliar application, particularly at the highest rate of 300 mg L^{-1}, significantly increased the vegetative growth parameters, NPK in leaves, plant dry weight, and fruit yield of tomato plants grown in newly reclaimed calcareous soil (24.9% total calcium carbonate) in comparison to the control. Ikram et al. (2024) noticed a similar pattern in tomatoes cultivated in clay loam soil as a pot experiment; they discovered that foliar ascorbic acid treatment increased significantly or insignificantly tomato yield, yield components, plant dry weight, and NPK content in plant samples in both saline and non-saline conditions. Furthermore, under clay soil conditions, Fouda & Abd-Elhamied (2017) noticed that ascorbic acid foliar application had a significant and substantial effect on eggplant vegetative growth measurements, yield, yield components, NPK, and chlorophyll content, as well as on the quality of fruits as compared with the control. Generally, many published studies have shown that administering ascorbic acid foliar application at the proper dose improves yield, yield components, dry yield, protein and NPK absorption for a variety of vegetables and field crops grown in different soil textures, such as cabbage grown in clay soil (Mosa & Ramadan, 2011); wheat grown in different soil textures (Bunder 2025; Diab *et al.*, 2017); sunflowers grown in sandy clay loam soil containing 8.2% calcium carbonate (Abdel-Hafeez *et al.*, 2019); barley grown in clay soil (Othman, 2021); maize grown in sand clay loam soil (Baddour et al., 2017) and lavender grown in sandy soil (Hashem, & Hegab, 2018). Vitamins B1 (thiamin) affect plant growth, yield and NPK content as follows; Aminifard *et al.* (2018) regarded that the performance of vegetative growth, yield, dry leaf, dry root and NP in leaves of fenugreek and coriander grown in loam sand soil were enhanced by the thiamin (B1) foliar spray at all rates (250, 500 and 750 ppm). A similar result was observed by Farouk *et al.* (2012) in tomato shoot fresh and dry weight and some physiological characteristics (chlorophyll, potassium, phosphorus, nitrogen, and total carbohydrate content) in the shoot of tomato grown in clay soil as a result of thiamin foliar application. Additionally, the application of thiamine or nicotinamide at doses between 50 and 100 mg L^{-1} improves the development and grain yield of soybean plants, making it possible to use them as a biostimulant (Alves *et al.* 2025). Concerning Vitamins B2 (riboflavin), Abood & Abdulhameed (2017) presented that the majority of sorghum yield and vegetative development characteristics were enhanced by foliar application of riboflavin by 300 mg L^{-1}. Furthermore, Wu *et al.* (2025) reported that riboflavin foliar application at 20 mg·L^{-1} enhances fragrant rice yield and quality. Finally, Belal *et al.* (2016) emphasized that single applications of amino acids or in a mix with vitamins B1 or B2 foliar spray in flame seedless grapevines were efficient in upgrading leaf surface area, shoot length, total amino acids and total chlorophyll in the leaves, enhancing percentages of Mg, P, N and K in the leaves as well as augmenting yield and yield components as compared with untreated treatment (control) in two seasons of study. The increase in onion productivity in our experiment can be attributed to the different roles of vitamins C, B1, and B2 in plants. According to numerous studies, ascorbic acid is a crucial non-enzymatic antioxidant that promotes plant growth and development, cell division and differentiation, cell wall expansion and growth, cell expansion and enlargement and improves membrane integrity, which may lead to reduced ion leakage (Akram *et al.*, 2017; Mohamed *et al.*, 2020; Hassan *et al.*, 2021, Tunçtürk *et al.*, 2024). Ascorbic acid reduces leaf senescence, increases leaf area, and increases photosynthetic pigment concentration in the form of chlorophyll A, chlorophyll B, and carotenoids (Hassan et al., 2021; Akram et al., 2017; Kanwal *et al.*, 2024). Also, it has increased the efficiency of photosynthesis, protects chloroplasts from oxidation, and improves the properties of stomata and gas exchange (Mosa & Ramadan 2011; Alamri *et al.*, 2018; Hassan *et al.*, 2021).

Furthermore, ascorbic acid has a role in regulating many biochemical and physiological processes, acts as a catalyst for many enzymes, stimulation respiration, regulation of flowering and root development (Diab *et al.,* 2017; Mohamed *et al.,* 2020; El-Mahdy, 2021). On the other side, thiamine (vitamin B1) is essential for primary metabolism for everything alive; its active form is thiamine pyrophosphate (TPP) (Raschke *et al.,* 2007; Ahmed & Abd El Sattar, 2024). Thiamine pyrophosphate controls many metabolic activities, such as the citric acid cycle (Krebs cycle), glycolysis, the Calvin cycle, directly related to chlorophyll contents in leaves, nitrogen assimilation, amino acid metabolism, branched-chain amino acid synthesis, protein synthesis, and nucleic acids (Aminifard *et al.,* 2018; Amjad *et al.,* 2021). TPP is acting as an important coenzyme for enzymes involved in chloroplast photosynthesis and the production of ATP (Al-Sultani and AlFahham, 2021). Recently, it was discovered that thiamine plays a protective role in plants during exposure to environmental stress and improves plant tolerance to adverse environmental conditions by preventing DNA damage (Raschke *et al.*, 2007; Aminifard *et al.,* 2018). Under abiotic stress conditions, more reactive oxygen species (ROS) are generated; hence, thiamine works to reduce various ROS and enhance plant tolerance. Among abiotic stress conditions that generated more ROS, drought (Ghaffar *et al.,* 2019; Amjad *et al.,* 2021; Jabeen *et al.,* 2021) and heavy metals (Al-Hakimi & Hamada, 2011; Sanjari *et al.,* 2019; Atif *et al.,* 2022). Riboflavin (vitamin B2) is an important micronutrient whose biochemical function is as a precursor to the coenzymes flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN), which are essential for biochemical reactions in all living cells where they participate in redox reactions (Averianova *et al.,* 2020; Wu *et al.,* 2025). These flavocoenzymes take part in the metabolic process of lipids, carbohydrates, proteins, and ketone bodies from which living organisms obtain most of their energy. (Averianova *et al.,* 2020). In general, riboflavin is a cofactor for various enzymes that are convertible between the oxidized and reduced forms; furthermore, riboflavin stimulates the mobilization of iron and transforms tryptophan into niacin and vitamins B9 and B6 into their active forms (Averianova *et al.,* 2020). Also, riboflavin works to reduce ROS and enhance plant tolerance to abiotic stress such as salinity (Jiadkong *et al.,* 2024). All of these facts support our conclusions that thiamine and riboflavin are effective in boosting onion crop development.

Under normal conditions, as in our study, foliar application with microbial gibberellic acid and vitamins (especially microbial ascorbic acid and microbial riboflavin) led to the best results in onion productivity. This onion productivity increases probably due to the role of gibberellic acid or vitamins or a combination between them in stimulating roots growth, consequently leading to more absorption of water and nutrients and increase their concentration in plant tissues, improving canopy growth and yield and yield components, which agrees with the results of Akram *et al.,* 2017; Younis *et al.,* 2020; Islam *et al.,* 2021; Alves *et al.,* 2025 and Sorour *et al.,* 2025. On the other hand, many researchers have drawn the same explanation but under stress conditions such as salinity (Ahmed & Abd El Sattar, 2024; Tunçtürk *et al.,* 2024), heavy metals (Alamri *et al.*, 2018; Emamverdian *et al.*, 2020), and drought stress (Kausar *et al.,* 2023). Also, Saeidi-Sar *et al.* (2013) indicated the positive effect of the interaction between gibberellic acid and vitamin C in reducing the harmful effects of salt stress on the common bean productivity as compared to adding both of them individually or the control treatment.

2 Water productivity

Many researchers have suggested calculating the WUE and/or IWUE of the onion fresh bulb yield as accepted measurements for evaluating the water productivity. However, calculating the WUE and/or IWUE of onion dry bulb yield was suggested by Zahran (2025) on the basis that the dry bulb yield of onions is more important than the fresh yield. Not only that, but he suggested calculations of WUE and/or IWUE for oil yield in oil crops and sugar yield in sugar crops. Regarding this study, foliar application of microbial gibberellic acid, vitamin treatments (C or B1 or B2 from microbial or chemical sources), and interaction between the two factors highly significantly or significantly improved water productivity (WUE and IWUE) for fresh and dry total onion bulb yield as compared with the control. In this respect, researchers have found that applying gibberellic acid externally at the right dosage boosts WUE or/and IWUE in different textural soil for a range of different vegetable and field crops like sweet sorghum grown in sandy soil (El-Kady *et al.* 2019), maize grown in sandy soil (EL-Edfawy *et al.*, 2021), summer cowpea grown in sandy loam (Arun *et al.*, 2017), faba bean grown in clay loam soil (Rady *et al.*, 2021), lettuce and rocket grown in hydroponic floating system (Miceli *et al.*, 2019). The rises in WUE and IWUE brought about by GA_3 foliar application generally can be attributed to the role of GA_3 in increasing growth, yield, and yield components, and increasing water absorption. In this respect, Islam *et al.*, (2021) specified that applying GA_3 to mungbean improved the root growth, which might help to uptake more water in plants; additionally, gibberellic acid's positive impact on various morphological and physiological processes (biomass accumulation, leaf expansion, and stomatal conductance) may be the cause of the higher water use efficiency (Miceli *et al.* 2019).

Concerning vitamin treatment, microbial ascorbic acid produced the highest effect in WUE and IWUE for fresh and dry onion bulb yield, then microbial riboflavin, followed by chemical thiamine. In this regard, scientists have discovered that external application of vitamin C at the appropriate dose increases WUE and/or IWUE in various textural soils for a wide range of veggies and crops, including maize grown in loamy soil (Kotb *et al.* 2021), sesame grown in clay loam soil (Abdo *et al.*, 2018), and sunflower grown in sandy soil (Saudy *et al.*, 2023). On the other hand, El-Bassiouny *et al.* (2023) reported that the application of thiamine as a foliar application enhancement the WUE of wheat grown in sandy soil. The rises in WUE and IWUE brought about by foliar vitamin application generally can be attributed to its role in increasing yield and increasing water absorption. Accordingly, Kausar *et al.* (2023) demonstrated that the use of thiamine (both 500 and 250 ppm) not only alleviated the drought stress but also improved the dry and fresh weight of the pea roots and shoots, yield components, and yield quality.

3 Soil properties

Before discussing the results of the soil, we must consider that onions are a crop with shallow roots. Its roots can penetrate around 18 cm (Terán-Chaves *et al.*, 2023). Consequently, the most important results will be found at this depth (0-0.20 m). Based on a statistical analysis of soil available NPK, pH, EC and OM content in 0-0.20 soil depth, it was found that microbial gibberellic acid had achieved significant improvement on only soil available NP and EC in both seasons. While vitamins showed insignificant differences in all tested soil parameters in both seasons. Available soil NP showed significant augmentation in the interaction between the two factors. Concerning gibberellic acid, Hussain et al. (2018) reported that foliar application of zinc plus gibberellic acid to lentil plants grown in sandy soil resulted in the significantly highest soil available NPK (24.0, 2.7, and 90.0 mg kg-1, respectively) after harvesting among other treatments, while foliar application with zinc had the modist soil available NPK (22.1, 2.4, and 90 mg/kg, respectively), and the lowest value was achieved in the control treatment (20.0, 2.1, and 65.0 mg/kg, respectively). Also, in sandy soil, Rashad (2020) added that soaking wheat seeds in gibberellic acid as an organic solution before cultivation increased available soil N significantly by 7.5% and increased available soil P by 3.89% at the end of the experiment (after harvesting) compared with the control. Furthermore, El-Edfawy *et al.* (2021) concluded that the foliar application of various concentrations of gibberellic acid to maize plants resulted in significant improvements in the sandy soil's available N, but available soil PK was not significantly affected by different treatments of gibberellic acid. In reference to vitamins, many researchers have demonstrated the same direction in no change about soil available NPK by foliar ascorbic plus citric acids application on wheat and maize grown on clayey soil (El-Maddah *et al.*, 2012). In contrast, many researchers observed an improvement in soil available NPK induced by foliar ascorbic acid in eggplant grown on clay soil (Fouda & Abd-Elhamied, 2017) and lavender grown in sandy soil (Hashem & Hegab, 2018). On the other hand, many investigators presented another opposite trend with decreasing soil available NPK by foliar ascorbic acid in faba bean grown on clay soil (El-Mahdy et al., 2021); barley grown on clay soil (Othman, 2021); and wheat grown in a pot experiment with sandy loam soil (El Azab, 2012). Generally, the articles on the effect of gibberellic acid and/or vitamins on soil-available nutrients are few. But, in general, plants exposed to nutrient deficiencies, as is the case in our study on calcareous sandy soils, have mechanisms of adaptation and increased nutrient availability in the root zone (Rengel & Marschner, 2005). These mechanisms are mainly dependent on the physiological and morphological characteristics of roots, such as root growth, distribution, and root hair formation. In general, these mechanisms improve with the improvement of root weight as a result of good treatments added to the soil or plant, which leads to an increase in the availability of nutrients in the soil, especially those available through diffusion, such as potassium and phosphorus, due to the restriction of their movement (Lynch, 2007; Rengel & Marschner, 2005). In this regard, many researchers explain that gibberellic acid plays a role in enhancing root growth, branching, and capillary capacity, improving water/nutrient uptake and canopy development (Khan *et al.*, 2006; Islam *et al.*, 2021). Similarly, vitamins C or B1 boost root formation, nutrient absorption, and canopy growth (Ahmed & Abd El Sattar, 2024; Alamri *et al.*, 2018; Kanwal *et al.*, 2024; Pradi-Vendruscolo & Seleguini, 2020). On the other hand, roots produce exudates; consequently, increasing roots may increase exudates. Through root exudation, plants continuously discharge a wide range of monomeric carbon (C) compounds into the rhizosphere. Root exudates account for about 5-21% of the carbon fixed in photosynthesis (Maurer *et al.*, 2021). These exudates from plant roots are a complex mix of purines, organic acid anions, nucleosides, phytosiderophores, inorganic ions (e.g., H+, HCO_3^-, OH^-), sugars, gaseous molecules (H2, CO2), vitamins, purines, amino acids, enzymes, and root border cells. These significantly improve pH in the soil surrounding the rhizosphere; consequently, augmented soil-available nutrients and plant uptake (Dakora and Phillips, 2002). In addition, a confirmed positive correlation between total organic acids, citric acid, and malic acid as root exudates and the population of phosphate-solubilizing bacteria, consequently increases available P, while the acetic acid, oxalic acid as root exudates were closely related to the population of nitrogen-fixing bacteria, Azotobacter, consequently increasing available N (Anandyawati *et al.*, 2017).

CONCLUSION

Enhancing crop/water productivity and nutrient absorption while reducing over-irrigation and mineral fertilizers is critical for soil fertility, biodiversity, environmental health, and food safety. However, modern agriculture struggles with chemical enhancers that degrade soil, harm biodiversity, and threaten human health. Microbial alternatives offer an eco-friendly, cost-effective resolution. Foliar microbial GA_3 application or/and vitamin (chemical vitamin B1, vitamin C or B2 from microbial and chemical sources) treatments significantly improved the productivity of onions (dry matter content, NPK uptake, protein yield, and total fresh and dry bulb yield), water productivity (water use efficiency and irrigation water use efficiency for total fresh and dry bulb production) and enhanced or maintained soil fertility (available NPK, OM content, pH, and

EC) over both research seasons. The best results were obtained when foliar application of microbial GA_3 with vitamins, especially microbial ascorbic acid. Foliar application of microbial ascorbic and gibberellic acids, combined with proper fertilization and irrigation, enhances onion/water productivity and sustains sandy calcareous soil fertility. Further research is required to assess the effects of microbial GA_3 combined with vitamins on foliar and soil applications regarding crop yield, soil health, and soil biodiversity.

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التأثيرات المتكاملة لحامض الجبريليك الميكروبي والفيتامينات على امتصاص العناصر الغذائية وإنتاجية البصل والماء وخصوبة التربة الجيرية

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الملخص العربي

الأمن الغذائي العالمي مُعرَّض للخطر بسبب تزايد الضغوط البيئية، وتقلص المساحات المزروعة، وانخفاض إنتاجية المحاصيل. ومن ثم، أصبحت التقنيات الميكروبية ذات أهمية حيوية للزراعة المستدامة. لا تتوفر معلومات كافية حول كيفية تأثير حمض الجبريليك الميكروبي (GA_3) والفيتامينات الميكروبية على إنتاجية الماء والبصل، وحالة العناصر الغذائية في النباتات والتربة. لسد هذه الفجوة، أُجريت تجربتين حقليتين في مزرعة ذات تربة رملية جيرية خلال موسمين شتويين متتاليين. أُجريت المعاملات في القطعة الرئيسية (بدون حامض الجبريليك الميكروبي وإضافة حامض الجبريليك الميكروبي)، وست معاملات في القطعة الفرعية (كنترول، الثيامين الكيميائي، حمض الأسكوربيك الميكروبي، حمض الأسكوربيك الكيميائي، الريبوفلافين الميكروبي، والريبوفلافين الكيميائي). أوضحت النتائج أن المعاملات الورقية من حمض الجبريليك الميكروبي أو معاملات الفيتامينات أدت إلى تحسن إنتاجية البصل بشكل معنوي (إجمالي إنتاج البصل الطازج والجاف، محتوى المادة الجافة، وامتصاص النيتروجين والفوسفور والبوتاسيوم، وإنتاج البروتين) وإنتاجية المياه (كفاءة استخدام المياه وكفاءة استخدام مياه الري المحسوبين لإنتاج البصل الكلي الطازج والجاف) وتحسن أو الحفاظ على خصوبة التربة (محتوى النيتروجين والفوسفور والبوتاسيوم الميسر وال pH وال EC ونسبة المادة العضوية) في كلا الموسمين. أظهرت معاملة حمض الأسكوربيك الميكروبي أداءً أفضل من معاملات الفيتامينات الأخرى في معظم القياسات المختبرة. أدى الرش الورقي لحمض الجبريليك الميكروبي مع الفيتامينات، وخاصة حمض الأسكوربيك الميكروبي والريبوفلافين الميكروبي، إلى تحسن أكبر في القياسات التي تم تقييمها. يُعد رش حمض الجبريليك الميكروبي مع الفيتامينات الميكروبية محفزًا حيويًا فعالًا للنبات وصديقًا للبيئة ومنخفض التكلفة، ويمكن استخدامها بأمان في التربة منخفضة الخصوبة لتحسين إنتاجية البصل والمياه وزيادة او المحافظة على خصوبة التربة.