

## The effect of super nano fertilizer on the qualitative and chemical indicators and the content of some active compounds in broccoli hybrids

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### Abstract

The field experiment was conducted at the training farm in Al-Muhnawiya, 40 km north of the center of Babil Governorate, to study the effect of super nano fertilizer on the qualitative and chemical indicators and the content of some active compounds in the curd. The experiment included two factors: the first was two broccoli hybrids (Besty F<sub>1</sub> green and Purple Magic purple) and the second was the method of adding super nano fertilizer (comparison, addition of super nano fertilizer to the soil, spraying nano fertilizer on the leaves). The experiment was designed according to the split plot system using a randomized complete block design with three replicates. The results of the experiment were statistically analyzed according to the analysis of variance method and according to the significant differences between the treatments at a probability level of 0.05 using the least significant difference (LSD).

The results indicated that the Besty F<sub>1</sub> hybrid was superior in terms of the percentage of carbohydrates and protein, the percentage of nitrogen, phosphorus and potassium, the percentage of soluble solids and glutathione compound in the curd, and the total chlorophyll content of the leaves (7.22% , 3.55%, 0.56%, 0.14%, 3.98%, 6.71%, and 64.20 mg. kg<sup>-1</sup>, 173.07 mg.100 g/fresh weight) respectively, while the Purple Magic F<sub>1</sub> hybrid exceeded the flower bud content of ascorbic acid and sulforaphane compound (132.20 mg.100 g<sup>-1</sup>. fresh weight, 364.14 mg/kg). Super nano fertilizer with soil treatment outperformed foliar spray treatment in terms of the percentage of carbohydrates and protein, the percentage of nitrogen, phosphorus and potassium, the percentage of dissolved solids, ascorbic acid, clothianidin, and sulforaphane in the plant's curd, and total chlorophyll in the leaves with values of (7.43%, 3.90%, 0.62%, 0.16%, 4.34%, 7.57%, 144.29 mg.100 g<sup>-1</sup> fresh weight, 72.57 mg. kg<sup>-1</sup>, 403.20 mg. kg<sup>-1</sup>, 193.00 mg.100 g<sup>-1</sup> fresh weight) respectively.

**Key words: Broccoli, nano Fertilization, Food production, Active compounds.**

## Introduction

Broccoli (*Brassica oleracea* L.var italica Plenck) belongs to the Brassicaceae family and is derived from wild species that grow on the northern coast of the Mediterranean Sea, from the borders of Greece to the British Isles and Western Europe [30]. Broccoli is an edible vegetable whose flower heads are eaten [26]. The area planted with broccoli in Iraq reached 804 hectares, with a production of 12,400 tons, resulting in a yield of 9.7 tons per hectare. This compares to the area planted worldwide, which reached 1,400,000 hectares with a production rate of 26,000,000 tons, meaning that the production rate per hectare is 19 tons [17].

Cruciferous vegetables are known to be a rich source of health-promoting phytochemicals [24], while broccoli is an important source of biologically important compounds [39]. These are associated with their high content of glucosinolates, isothiocyanates, phenolic compounds, ascorbic acid, tocopherols, carotenoids, and minerals such as calcium, magnesium, sulfur, and selenium. The phytochemicals that are formed in vegetable crops are mainly controlled by genetics and environmental conditions [28]. Broccoli provides numerous health benefits through its flower buds (the edible part), as it contains compounds such as indole-3 -carbinol, sulforaphane, flavonoids, and vitamins such as A, B, and C. It is high in fiber and almost fat-free, making it an ideal food for weight loss diets [25]. Essential nutrients must be present in sufficient and balanced quantities for plants to grow and produce the best results, especially broccoli, which has health benefits that may not be found in many other vegetables. In order to compensate for the lack of nutrients in the

soil, we currently use chemical fertilizers in enormous quantities. However, the continued use of chemical fertilizers poses health and environmental risks, including the potential for nitrate leaching to contaminate surface and groundwater [16]. The uncontrolled use of chemical fertilizers has had harmful effects, including groundwater and soil contamination and increased salinity. As a result, scientists have investigated the possibility of using nanotechnology to increase fertilizer efficiency, which has been termed “nano fertilizer.” In addition to maintaining soil health and environmental cleanliness, it reduces nutrient loss and increases plant productivity [5]. Thanks to their effective properties, such as rapid absorption by plants, large surface area, and release of nutrients on demand, nano fertilizers and nano nutrient coatings have recently gained popularity as a means of enhancing plant growth and productivity in fertilization programs [4]. Ultimately, nano fertilizers are the most technically advanced method of supplying crops with mineral nutrients compared to traditional chemical fertilizers, providing them with the nutrients necessary to meet plant needs, reducing losses, and thus improving fertilizer use efficiency [36]. It should be noted that the dual application of nano fertilizers may create a continuous nutritional balance for the different growth stages of the plant (broccoli) and a better environment for nutrient absorption in the plant. The current study aims to

- 1- Testing the cultivation of two hybrids of green and purple broccoli under the conditions of Babil Governorate and selecting the best suitable variety in terms of growth and active compounds.
- 2- Finding the best method for adding super-

nano fertilizer to increase growth indicators and the content of active compounds in two broccoli hybrids.

### Materials and Methods

The experiment was conducted at the training farm in the Mahnawiya region district (40 km) north of the center of Babil province, at a longitude of 44.5E and a latitude of 32.7 N, during the autumn agricultural season (2024-2025), to study the effect of super nano fertilizer on the quality and chemical indicators of broccoli plants. Field soil samples were taken before planting to study physical and chemical properties randomly (table 1) from different areas at depths ranging from 0 - 30 cm, then air-dried, ground, passed through a sieve with a diameter of 2 mm, and analyzed to determine some of the chemical and physical properties of the field soil at the Central Soil Laboratory/Babel Agriculture Directorate. The field soil designated for the experiment was prepared by removing plants and bushes, then plowing, smoothing, and leveling it well. The land was then divided into six plots, each plot being a duplicate with a width of 1m per plot, and each unit measuring 3 x 1 (length x width). The distance between each plot was 1 m, with a distance of 0.75 m between the experimental units as a buffer to prevent mixing between treatments, leaving a buffer distance at the beginning and end of each sector. A drip irrigation system was used. Using a randomized full block design in accordance with the split plot system with three replicates, the experiment was carried out as a 2x3 factorial. The first factor (A1, A2) is represented by the hybrids, and the second factor is represented by the techniques used to apply super nano fertilizer. There were eighteen experimental units in the per replication. The green F1 Besty Broccoli from the Swiss business

Syngenta and the purple Purple Magic F1 from the German company Bobby-Seeds were used as broccoli seeds for the hybrids. The seeds were sown on 27/8/2024 in plastic trays filled with potting soil in one of the model nurseries in the Imam district of Babil province, with one seed per cell under a green mesh cover to reduce sunlight and provide good conditions for seedling growth. After the seedlings reached the four to five true leaf stage, they were transferred to the field on 3/10/2024 for the agricultural season and planted in beds at a rate of 12 seedlings per experimental unit, distributed on both sides of the row, with a distance of 50 cm between rows and 50 cm between plants. Cultural Practices, irrigation, and pest control were carried out as recommended [1]. A drip irrigation system was used twice a week during the early stages of seedling growth and thereafter according to the actual needs of the plants and environmental conditions. The experiment included two factors: The first factor is two hybrids of broccoli plants

- Green variety Besty Broccoli F1: Produced by the Swiss company Syngenta with a germination rate of 97% and purity of 99.9% Maturation period 85-90 days Head weight 350 grams.
- Purple variety Purple Magic F<sub>1</sub>: Produced by the German company bobby-seeds with a germination rate of 98% and purity of 100%. Maturation period 70-85 days with a head weight of 400 grams.

The second factor was super nano fertilizer, which was added in two ways:

- Control treatment (without fertilization).
- Addition of super nano fertilizer to the soil at a rate of  $2 \text{ g L}^{-1}$ .
- Foliar spraying of super nano fertilizer at a rate of  $2 \text{ g L}^{-1}$ .

The direct ground application under the seedlings is done using Super nano fertilizer produced by Al-Khudra, an Iranian company, in three doses with a 14-day interval between each dose. The fertilizer is dissolved in water and applied under the seedlings according to the company's recommendation with a concentration of (2 g. L<sup>-1</sup>). per liter). And within the limits of the water requirement for the crop. And three foliar sprays, with a 14-day interval between each spray, at a concentration of (2 g. Liter-1) (with the addition of a concentration of 1 mL L<sup>-1</sup> of the spreading agent (20 Tween) to the solution to reduce the surface tension of water and increase the adhesion of the solution to the leaves and fruits, thereby increasing absorption. The spraying process occurs during the early morning hours until complete wetting using a 20-liter electronic sprayer.

Six plants were randomly selected from each experimental unit to measuring the qualitative indicators and broccoli content of some active compounds. The results of the experiment were statistically analyzed according to the analysis of variance method and according to the least significant difference (L.S.D.) test between treatments at a probability level of 0.05 [2]. The GenStat program was used for statistical analysis. The indicators studied were as follows:

- Percentage of carbohydrates (%) in the curd

The percentage of carbohydrates was estimated according to the method described in [20].

- Percentage of protein (%) in the curd

The Keldahl method was used to estimate the protein percentage in the samples, based on the method mentioned by [38].

- Percentage of nitrogen (%) in the curd

Estimated according to the Kaldor method as mentioned in [21].

- Percentage of phosphorus (%) in the curd

The phosphorus content of the plant was estimated based on the method provided by [13].

- Percentage of potassium (%) in the curd

The potassium content in plant samples (which were collected, dried, and ground) was determined, where the plant powder was digested using the acid digestion or wet washing method according [12].

- Percentage of total soluble solids %TSS in the curd

This ratio (Total soluble solid) was measured by placing drops of juice from the curd using a Hand Refractometer.

- Concentration of ascorbic acid (vitamin C) ( $\text{mg.100 g}^{-1}$  FW) in the curd

The ascorbic acid compound was measured in the laboratories of the Scientific Research Authority / Environmental Research Center using the spectrophotometric method according to [11].

- Estimated total chlorophyll in leaves (mg.100 g<sup>-1</sup> FW)

The total chlorophyll pigment in the leaves was estimated by taking random samples from five plants for each experimental unit. The samples were then washed with water and air-dried. One gram of fresh weight was taken, to which 10 ml of 80% acetone was added. The leaf tissue was ground using a porcelain mortar, and the solution was filtered using filter paper (Wathmann No.1). The grinding process was repeated to extract the remaining pigments until the tissue turned white. The total filtrate volume was then completed to 20 ml with acetone[19].And a spectrophotometer was used to measure the absorbance of the

pigments at wavelengths of 645 and 663 nanometers, then the total chlorophyll content was calculated.

- Estimated glutathione (mg.kg) in the curd

Glutathione was extracted according to the method presented by the scientist [32].

- Estimated sulforaphane (mg.kg) in the curd

The compound Sulforaphane was measured in the laboratories of the Scientific Research Authority / Center for Environmental and Water Research using the (HPLC) device according to the method mentioned by[14].

Table 1: Physical and chemical properties of the field soil before planting

Property	Unit	Value	Property	Unit	Value
Soil PH	–	7.14	Available Potassium	mg/kg	31.7
Electrical Conductivity	ds/m	3.0	Bulk Density	g/cm <sup>3</sup>	1.12
Organic Matter	%	11.5	Sand	g/kg	176
Available Nitrogen	mg/kg	12.3	Silt	g/kg	484
Available Phosphorus	mg/kg	9.52	Clay	g/kg	340
Soil Texture	–		Loamy clay silt		

Table 2: Chemical analysis of super nano fertilizer

N	P	K	Fe	Zn	Mn
%6	%3	%17	%4	%4	%2
Cu	B	Mo	Ca	Mg	S
%0.5	%0.5	%0.1	%1	%3	%6

## Results

Qualitative and chemical indicators in the curd.

The results in Table 3 indicate significant differences between the two broccoli hybrids in terms of qualitative indicators in the curd. The Besty F1 hybrid outperformed the other hybrid in all qualitative and chemical indicators in broccoli flower heads, including the percentage of carbohydrates and protein and the percentage of nitrogen, phosphorus, and potassium, respectively (7.22%, 3.55%, 0.56%, 0.14%, 3.98%). When treated with super nano fertilizer, significant differences appeared in the chemical indicators in the curd, with soil treatment outperforming foliar spraying in

the percentages of carbohydrates, protein, nitrogen, phosphorus, and potassium with values of 7.43%, 3.90%, 0.62%, 0.16%, and 4.34%), respectively. The binary interactions of the hybrid treatment and super nano fertilizer showed significant differences in the qualitative and chemical growth indicators in the curd through the interaction between the Besty F1 hybrid and the soil treatment of super nano fertilizer, which recorded the highest average in all percentages of carbohydrates, protein, nitrogen, phosphorus, and potassium, (7.78%, 4.01%, 0.64%, 0.20%, and 4.43%), respectively.

Table 3: Effect of hybrids, super nano fertilizer and their interaction on the qualitative and chemical indicators of broccoli curd.

Hybrid	Percentage of carbohydrates in curd%	Percentage of protein in curd%	Percentage of nitrogen in curd %	Percentage of phosphorus in curd%	Percentage of potassium in curd%
Besty F1	7.22	3.55	0.56	0.14	3.10
Purple MagicF1	6.62	3.32	0.53	0.09	3.79
L.S.D.0.05	0.009	0.006	0.0008	0.0058	0.027
Super Nano Fertilizer					
control	6.32	2.90	0.46	0.07	3.34
Ground treatment	7.43	3.90	0.62	0.16	4.34
Foliar spraying	7.01	3.52	0.56	0.12	3.97
L.S.D.0.05	0.019	0.019	0.0031	0.0017	0.013
Super Nano Fertilizer X Hybrid					
A1C0	6.56	3.00	0.48	0.07	3.45
A1C1	7.78	4.01	0.64	0.20	4.43
A1C2	7.31	3.65	0.58	0.15	4.06
A2C0	6.08	2.79	0.44	0.06	3.24
A2C1	7.08	3.80	0.60	0.11	4.25
A2C2	6.70	3.38	0.54	0.09	3.87
L.S.D.0.05	0.023	0.023	0.0036	0.0044	0.022

\*A1= Besty F1 A2= Purple MagicF1

C0=Control C1= Ground treatment C2= Foliar spraying

Curd content of some active compounds.

The results in Table 4 indicate significant differences between broccoli hybrids for some active compounds, except for the percentage of soluble solids (TSS), which showed no significant difference. The Purple Magic F1 hybrid was superior in ascorbic acid and sulforaphane content (132.20 mg/100 g fresh weight, 364.14 mg/kg kg<sup>-1</sup>), while the Besty F1 hybrid excelled in total chlorophyll and clothianidin content (173.07 mg.100 g<sup>-1</sup> fresh weight, 20.64 mg. kg<sup>-1</sup>). When treated with Super Nano fertilizer, significant differences appeared in the active compounds, soil treatment outperformed foliar spraying in terms of the average percentage of total dissolved solids (TSS), ascorbic acid concentration, total chlorophyll content in leaves, and average glutathione and sulforaphane content, with values of 7.57%, 144.29 mg.100 g<sup>-1</sup> fresh

weight, 193.00 mg.kg<sup>-1</sup>, 72.57 mg. kg<sup>-1</sup>, and 403.20 mg. kg<sup>-1</sup>, respectively. The results indicate that the two-way interactions of hybrid treatment and super nano fertilizer showed significant differences in the active compounds through the interaction between the Besty F1 hybrid and the ground treatment of nano fertilizer, which recorded the highest average percentage of total dissolved solids (TSS) and glutathione compound in the leaves and total chlorophyll content in leaves (7.71% and 76.81 mg.kg<sup>-1</sup> and 401.89 mg.100 g<sup>-1</sup> fresh weight), respectively. The interaction between the Purple Magic F1 hybrid and the soil treatment with nano fertilizer exceeded the concentration of ascorbic acid and sulforaphane compound with values of (153.22mg.100 g<sup>-1</sup> fresh weight,420.99 mg.kg<sup>-1</sup>)

Table 4: Effect of hybrids, super nano fertilizer, and their interaction on the content of broccoli curd of some active compounds.

Hybrid	Total Soluble Solids (%T.S.S)	Ascorbic acid (mg/100 g fresh weight)	Total chlorophyll (mg/100 g fresh weight)	Glutathione (GSH) (mg/kg)	Sulforaphane (mg/kg)
Besty F1	6.71	119.17	173.07	64.20	338.46
Purple Magic F1	6.55	132.20	157.33	57.37	364.14
L.S.D.0.05	NS	1.87	5.79	0.441	1.578
Super Nano Fertilizer					
control	5.54	105.26	137.44	46.62	296.05
Ground treatment	7.57	144.29	193.00	72.57	403.20
Foliar spraying	6.79	127.51	165.17	63.16	354.64
L.S.D.0.05	0.12	0.56	0.67	0.416	1.195
Super Nano Fertilizer X Hybrid					
A1C0	5.67	100.60	142.56	48.91	287.43
A1C1	7.71	135.37	201.89	76.81	385.41
A1C2	6.76	121.53	174.78	66.86	342.52
A2C0	5.41	109.91	132.33	44.33	304.67
A2C1	7.44	153.22	184.11	68.33	420.99
A2C2	6.82	133.48	155.56	59.46	366.76
L.S.D.0.05	1.55	1.42	5.27	0.526	1.596

\*A1= Besty F1    A2= Purple MagicF1

C0=Control    C1= Ground treatment    C2= Foliar spraying

## Discussion

The two hybrids differed significantly in terms of qualitative and chemical growth indicators, including the percentage of carbohydrates and protein in the curd as well as the percentages of nitrogen, phosphorus, and potassium in the curd. The difference between the hybrids is due to genetic differences between the genetic makeup of both hybrids and the nature of genetic expression in response to the environmental conditions of the cultivated area, which leads to variation in growth rate [27]. The two hybrids also differed in terms of the plant's content of active compounds, except for the percentage of total soluble solids (TSS), which showed no significant difference. This may be attributed to their different genetic makeup, which differs physiologically in the metabolic representation of the raw materials formed by biological processes that affect their morphological characteristics, which in turn affects their productive capacity and the extent to which they are affected by environmental factors [29]. These results are consistent with the findings of [3]. The application of Super Nano fertilizer in both soil and foliar spray treatments had a significant effect on all qualitative and chemical indicators of growth in the curd, with the soil treatment exceeding (percentage of carbohydrates and protein and percentage of nitrogen, phosphorus, and potassium elements). This is because the fertilizer combination containing nutrients plays a role in increasing the availability of nutrients, thereby facilitating their absorption by plants and increasing their quantity within them, as well as building a root system that is highly efficient in absorbing major and minor nutrients, which helps increase the plant's biological activity and thus increase the proportion of nutrients,

including nitrogen, phosphorus, and potassium in the plant [6]. We note that nano fertilizers added to the soil make the roots highly capable of intercepting and absorbing nutrients from the soil solution. The phenomenon of mass flow of ions also plays a role in this area, as the elements are transferred to the surface of the roots with the movement of water. This mechanism helps the roots absorb the largest amount of nutrients due to the speed of movement, as the availability of water helps increase the movement of elements to the roots through mass flow and diffusion [33]. Similarly, nano-based fertilizers of major elements promote leaf growth and increase the nutrient and chlorophyll content in leaves [34]. In addition to the function of nanoparticles in modifying gene expression, which leads to biological processes that affect plant growth and development, the specific properties of nanoparticles also modify the physical and chemical properties of plants in ways that affect plant growth in different ways [7] in plant growth areas.

The increase in vegetative growth resulting from super nanotechnology treatment may be due to its physiological role in stimulating porphyrin molecules found in important metabolic compounds such as chlorophyll and cytochrome pigments, which are essential for photosynthesis and respiration, as well as coenzymes that activate phosphorus and are necessary for the function of many enzymes and the production of amino acids used in protein synthesis [31];[9].

Similarly, potassium is considered primarily responsible for enzymatic activity and protein structure stability. Accordingly, nitrogen plays an important role in the

synthesis of plant components, along with phosphorus, potassium, and other micronutrients that complement the role of macronutrients and amino acids by activating the action of various enzymes and synthesizing proteins [23], which positively affects plant growth and yield indicators.

Nano nutrients can increase chlorophyll levels by facilitating rapid access to nutrients at plant growth sites, increasing the rate of photosynthesis, chlorophyll production, and ultimately plant growth and development. They also affect the ability of the cuticle to absorb nanoparticles efficiently. For example, nanoparticles can affect the size of stomata and enter through them, and particle adhesion to leaves effectively affects the delivery of nanoparticles to plants [22]. These results are consistent with DeRosa et al. [15].

This increase in chlorophyll pigment may be due to the role of nano fertilizer in increasing elements and stimulating biological processes, including the formation of chlorophyll pigment, especially nitrogen, which plays a direct and important role in the formation of chlorophyll pigment, as nitrogen participates in the synthesis of

the four porphyrin groups (a group of pigments and iron) involved in chlorophyll synthesis [37], leading to an increase in chlorophyll content in plants. With regard to the production of active compounds, depending on glutathione and sulforaphane, this was enhanced by the application of micronutrients. Micronutrients in zinc and iron fertilizers (Table 2) perform vital functions for normal plant growth and metabolism, as they have a significant effect on the biosynthesis and regulation of hormones, chlorophyll and carbohydrate production, protein synthesis, photosynthesis, DNA stability/repair, membrane function, and enzyme activation [35];[18]. They are essential micronutrients and are key to more than 300 enzymes and hormones. Therefore, it can be concluded that when the availability and absorption of micronutrients increase, the accumulation of certain phytochemicals and secondary metabolites improves, due to improved plant metabolism and nutrient status [10]. The positive effect of nano fertilizers on chemical composition, such as ascorbic acid and total dissolved solids (T.S.S.), can be attributed to the presence of major nutrients (Table 2), indicating that Nano fertilizers appear to enhance the absorption and efficient use of nutrients by plants [8].

## Conclusion

The Besty F1 hybrid outperformed the others in terms of quality and chemical indicators and some active compounds, and the application of super nano fertilizer to the soil achieved the highest rate in quality and

chemical indicators and active compounds compared to foliar spraying. The dual interaction of the Besty F1 hybrid and soil treatment had a significant effect on most of the studied traits.

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