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Effect of nitrogen and phosphorus fertilizers on growth and biochemical composition of tomato (*Solanum lycopersicum*)

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Abstract. *Abdullah HA. 2025. Effect of nitrogen and phosphorus fertilizers on growth and biochemical composition of tomato (*Solanum lycopersicum*). Asian J Agric 9: 507-512.* Tomato (*Solanum lycopersicum*) is an economically important horticultural crop whose growth and quality are strongly influenced by nutrient management. Nitrogen (N) and phosphorus (P) are essential macronutrients that regulate plant metabolism, yet their combined effects on tomato performance under arid greenhouse conditions remain insufficiently explored. This study evaluated the interactive influence of ammonium sulfate and triple superphosphate on vegetative growth and biochemical composition of tomato. A completely randomized factorial design was applied with 16 N×P treatment combinations and three replications using 4 kg of soil per pot. Fertilizers were supplied in two equal splits at 10 and 25 days after seedling emergence, and plant responses were assessed after 52 days. Measurements included plant height, root length, shoot and root dry weights, leaf area, and concentrations of carbohydrates and proteins. Statistical analysis using two-way ANOVA and Duncan's test ($p \leq 0.05$) showed significant main and interactive effects of N and P. The combined application of 0.250 kg/ha N and 0.150 kg/ha P produced the best performance, with plant height nearly doubling compared to controls and protein content increasing by about one third. The synergistic effects of N and P were linked to enhanced photosynthetic capacity, stronger root development, and more efficient nutrient assimilation. These findings suggest that balanced fertilization strategies can improve both growth and nutritional quality of tomato while providing guidance for sustainable crop production in arid agroecosystems such as Iraq.

Keywords: Ammonium sulfate, biochemical composition, nitrogen, phosphorus, tomato

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is the most widely cultivated vegetable crop in the world due to its high economic value and nutritional content, including lycopene, vitamins, and essential minerals (Dubos et al. 2017). Its global demand, especially in developing countries, continues to increase and drives farmers and researchers to adopt modern cultivation techniques that improve both yield and quality under changing environmental conditions. Sustaining tomato production requires a clear understanding of plant physiological needs, particularly in regions affected by heat stress, expanding arid zones, and declining rainfall. Among the most critical factors influencing tomato growth are macronutrients, especially nitrogen (N) and phosphorus (P), which are fundamental to plant metabolic and structural development. Nitrogen is essential for chlorophyll formation, amino acid synthesis, and vegetative growth (Liu 2021; Reddy et al. 2025), while phosphorus plays a central role in ATP-mediated energy transfer, nucleic acid synthesis, and root system development (Naz et al. 2022). Although the independent effects of N and P have been extensively studied, their combined influence under arid and semi-arid conditions remains insufficiently understood (Wang et al. 2024).

Greenhouse cultivation provides a useful platform to evaluate nutrient interactions because it allows for environmental control and minimizes external disturbances that may confound plant responses. Studies under greenhouse conditions can thus reveal the specific roles of fertilization regimes on plant physiology and growth (Hao et al. 2023). However, the misuse of fertilizers in such systems can lead to soil acidification, nutrient leaching, eutrophication of water bodies, and the disruption of beneficial soil microbes (Wang et al. 2021). Hence, determining the appropriate balance of N and P is essential not only to maximize tomato production but also to safeguard soil and environmental health.

The interaction between N and P is central to plant growth and metabolism. Nitrogen stimulates protein synthesis and enzymatic activity, whereas phosphorus ensures that energy is available for these processes. When applied together, these nutrients strengthen photosynthesis, improve carbon assimilation, and support balanced resource allocation between vegetative structures and storage compounds such as carbohydrates (Sani et al. 2020; Ma et al. 2022). Recent findings indicate that combined fertilization enhances the activity of key enzymes such as nitrate reductase and RuBisCO, leading to more efficient nitrogen utilization and higher carbon fixation rates (Jin et al. 2023). Such evidence emphasizes the importance of co-limitation concepts, where the deficiency of one nutrient restricts the optimal use of another.

Research in cereals such as wheat and rice demonstrates that balanced application of N and P improves root system architecture, increases biomass, and enhances the nutritional value of harvested products (Ronga et al. 2020; Kareem et al. 2020). Comparable effects are expected in tomato, where improved vegetative growth is often linked with higher protein and carbohydrate contents. Despite these insights, studies in Iraq and other arid environments have mostly concentrated on crop yield, with limited focus on biochemical quality parameters such as nutrient composition (Rad et al. 2020; Khan et al. 2023). This gap in knowledge is particularly critical because sustainable agriculture in dry regions must not only secure yield stability but also ensure food quality and soil conservation.

Addressing these challenges requires precision fertilization strategies that integrate nutrient efficiency with environmental sustainability. In Iraq, where agricultural systems face combined pressures of climate change, water scarcity, and soil fertility degradation, evidence-based approaches to fertilizer management are urgently needed. Studies that simultaneously examine morphological traits and biochemical indicators can provide more comprehensive guidance for sustainable tomato production.

Therefore, this study was conducted to evaluate the combined effects of ammonium sulfate and triple superphosphate fertilizers on the vegetative growth and biochemical composition of tomato plants cultivated under greenhouse conditions in Mosul, Iraq. Specifically, the research aims to determine how different nitrogen and phosphorus application rates influence plant height, root development, biomass accumulation, and the concentrations of carbohydrates and proteins. The findings are expected to contribute practical recommendations for sustainable tomato farming in arid agroecosystems.

MATERIALS AND METHODS

Experimental design and location

The research took place at the Department of Biology greenhouse facility of the College of Education for Pure Sciences, University of Mosul, Iraq, during the 2023-2024 growing season. The site provided stable environmental conditions, which enabled precise control of temperature, humidity and light variables so that observed plant performance changes could be linked directly to fertilization treatments instead of environmental variations.

The research used a completely randomized design (CRD) factorial experiment to study N and P fertilization effects on their main and interactive levels. The experimental design consisted of 16 treatment combinations (Table 1), which used four N application rates (0.000, 0.180, 0.200, and 0.250 kg/ha as ammonium sulfate) and four P application rates (0.000, 0.120, 0.150, and 0.200 kg/ha as triple superphosphate). The experiment consisted of 48 experimental units because each treatment received three replications.

Soil preparation and pot setup

The College of Agriculture and Forestry at University of Mosul obtained cultivated field topsoil for collection. The soil samples underwent air drying followed by 2 mm mesh sieving and homogenization to achieve uniform particle distribution and minimize pot-to-pot variability. The physical and chemical properties of the soil received analysis before planting to determine its initial fertility status. The prepared soil filled each plastic pot (20 cm diameter) to a total weight of 4 kg. The selection of ammonium sulfate as nitrogen source depended on its 21% nitrogen content and its capacity to lower soil pH which benefits alkaline soil conditions found in the region. The selection of triple superphosphate as phosphorus source relied on its high water solubility and quick root availability.

Seed sowing and plant management

The Nineveh Seed Certification Center provided *Solanum lycopersicum* certified seeds to guarantee both genetic uniformity and high seed germination rates. The prepared pots received seeds which were planted at a depth of 1.5 cm. The initial sowing of multiple seeds in each pot allowed for proper germination before thinning the seedlings to maintain one plants per container.

The greenhouse environment maintained temperatures at 25±2°C while keeping relative humidity at 70±5% and providing a 12-hour photoperiod. The greenhouse received supplemental lighting at 250 µmol m^{-2} s^{-1} when natural light became insufficient. The soil moisture level remained at 70% of field capacity through regular watering practices which prevented both waterlogged and dry conditions.

Fertilizer application

The fertilizer applications were carried out in two equal splits: the first at 10 days after seedling emergence (DASE) and the second at 25 days after seedling emergence. The calculated amounts for each treatment were dissolved in water and applied directly to the soil surface to ensure uniform distribution and rapid nutrient availability. The N and P dosages were selected based on regional agronomic recommendations and previous experimental findings, balancing optimal plant growth with environmental safety to prevent nutrient leaching or accumulation.

Table 1. Experimental treatment combinations (N x P factorial design)

Nitrogen level (kg/ha)	Phosphorus level (kg/ha)	Treatment code
0.0	0.0	T1
0.180	0.0	T2
0.200	0.0	T3
0.250	0.0	T4
0.0	0.120	T5
0.180	0.120	T6
0.200	0.120	T7
0.250	0.120	T8
0.0	0.150	T9
0.180	0.150	T10
0.200	0.150	T11
0.250	0.150	T12
0.0	0.200	T13
0.180	0.200	T14
0.200	0.200	T15
0.250	0.200	T16

Note: This matrix allowed precise testing of factorial interactions between nitrogen and phosphorus on vegetative and biochemical traits

Morphological measurements

The following vegetative parameters were measured after 52 days of growth:

Plant height (cm): measured from the soil surface to the apical meristem using a ruler.

Root length (cm): determined after carefully washing roots free of soil.

Shoot and root dry weight (g): measured after drying plant parts in a hot-air oven at 70°C until constant weight.

Leaf area (cm²): measured using a digital planimeter on the largest fully expanded leaf per plant, not as total canopy leaf area.

Biochemical analyses

The phenol-sulfuric acid method measured carbohydrate content which resulted in mg/g dry weight values. The modified Lowry method (Lowry et al. 1951) measured crude protein content through peptide bond colorimetric detection which produced results as percentages of dry weight.

Statistical analysis

The two-way ANOVA analysis evaluated both nitrogen and phosphorus effects and their combined interaction. The Shapiro-Wilk test and Levene's test evaluated data normality and homogeneity of variances before statistical analysis. The Duncan's Multiple Range Test at $p \leq 0.05$ separated treatment means. The statistical analysis of this study used SPSS software version 25 for all procedures (Schleuss et al. 2020).

RESULTS AND DISCUSSION

Morphological responses to nitrogen and phosphorus fertilization

The application of nitrogen (N) and phosphorus (P) fertilizers either separately or together created noticeable variations in tomato plant (*Solanum lycopersicum*) vegetative development throughout 52 days of cultivation. As shown in Table 2, plant height ranged from 52.83 cm (T0) to 110.67 cm (N 0.250 × P 0.150), root length varied between 20.58 cm (T0) and 53.33 cm (N 0.250 × P 0.150), while shoot dry weight increased from 0.442 g in the control to 2.774 g under optimal fertilization. Similarly, root dry weight improved from 0.129 g in the control to 1.496 g in the optimal treatment, and leaf area showed limited variation (3.242-3.461 cm²), consistent across treatments. These results indicate that balanced N and P fertilization improved most morphological traits compared with unfertilized controls, with the combination of 0.250 kg/ha N and 0.150 kg/ha P generally producing the highest values.

The observed improvements can be mechanistically explained by the complementary roles of nitrogen and phosphorus in plant physiology. Nitrogen, through its role in chlorophyll synthesis and protein metabolism as reported in previous studies, directly stimulates photosynthetic capacity, while phosphorus ensures efficient energy transfer and root system development. This synergy is reflected in the superior growth responses obtained under combined treatments, compared with single-nutrient applications.

Biochemical responses: Carbohydrate and protein concentrations

The biochemical composition of vegetative tissues underwent significant changes because of fertilization (Tables 3 and 4). The carbohydrate content in control plants measured 1.050±0.05 mg/g dry weight but the optimal N×P treatment reached 1.667±0.09 mg/g dry weight, which represented a 58.8% increase. The plants showed better photosynthesis and their assimilates moved more efficiently toward storage compounds instead of building structural biomass. The protein content increased from 5.129±0.12% in the control to 6.869±0.14% when using the optimal fertilization regime. The combination of sufficient nitrogen assimilation into amino acids and protein synthesis became possible because phosphorus availability supported ATP production.

Table 2. Combined effects of nitrogen and phosphorus on morphological parameters of tomato plants

Nitrogen (kg/ha)	Phosphorus (kg/ha)	Plant height	Root length	Shoot DW	Root DW	Leaf area
0.0	0.0	52.83 ghi	20.58 hij	0.442 b	0.129 a	3.242 a
0.180	0.0	80.67 ef	34.00 efg	2.733 a	1.465 a	3.429 a
0.200	0.0	103.00 abc	45.00 bc	2.759 a	1.483 a	3.450 a
0.250	0.0	74.17 b	30.42 c	1.901 c	1.115 b	3.269 b
0.0	0.120	70.33 fgh	29.33 ghi	1.688 b	1.426 a	3.415 a
0.180	0.120	88.00 de	37.00 def	2.740 a	1.470 a	3.433 a
0.200	0.120	108.33 ab	46.33 b	2.764 a	1.490 a	3.454 a
0.250	0.120	79.25 ab	33.17 bc	2.158 b	1.392 a	3.423 a
0.0	0.150	73.00 fg	31.00 fgh	2.710 a	1.434 a	3.419 a
0.180	0.150	95.33 bcd	39.00 cde	2.748 a	1.474 a	3.440 a
0.200	0.150	110.67 a	53.33 a	2.774 a	1.496 a	3.461 a
0.250	0.150	83.50 a	36.50 a	2.428 a	1.414 a	3.428 a
0.0	0.200	75.00 fg	32.67 e-h	2.723 a	1.442 a	3.426 a
0.180	0.200	99.33 a-d	42.33 bcd	2.754 a	1.478 a	3.446 a
0.200	0.200	92.67 cde	38.33 cde	2.549 a	1.439 a	3.445 a
0.250	0.200	81.17 a	34.17 ab	2.402 a	1.405 a	3.429 a

Note: Means followed by different letters are significantly different at $p \leq 0.05$

The observed increase in carbohydrate concentration under the optimal fertilization regime likely reflects an upregulation of photosynthetic enzyme activity, notably ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), alongside improved translocation of photoassimilates to storage tissues. Protein accumulation, on the other hand, is indicative of enhanced nitrogen assimilation via the activation of nitrate reductase and glutamine synthetase pathways. Phosphorus availability ensures that these biosynthetic reactions are energetically sustained, thereby supporting amino acid synthesis and higher protein content. Similar biochemical patterns have been observed in other crops in legumes and rice under balanced N and P nutrition, underscoring the universal nature of this nutrient interaction across plant taxa (Hasan et al. 2016; Jin et al. 2023).

Integrated view of morphological and biochemical improvements

The composite bar chart (Figure 1) shows the simultaneous improvement of morphological and biochemical traits under optimal fertilization. The visual integration shows that the synergy between N and P nutrients affects both structural growth and metabolic processes. The optimal treatment led to increased plant height, root length and biomass production together with substantial increases in carbohydrate and protein content, which indicates that N and P work together to activate physiological pathways that improve both growth and nutritional quality.

Statistical significance and treatment ranking

The statistical analysis confirmed significant main effects for both nitrogen and phosphorus, as well as a significant N×P interaction for most parameters measured ($p \leq 0.05$). Duncan's test post-hoc comparisons showed that the 0.250 kg/ha N + 0.150 kg/ha P treatment was always the highest, while the unfertilized controls were always the lowest across traits. Treatments with high N but low P, or vice versa, produced intermediate results, reinforcing the concept that balanced nutrient supply is more effective than single-nutrient emphasis.

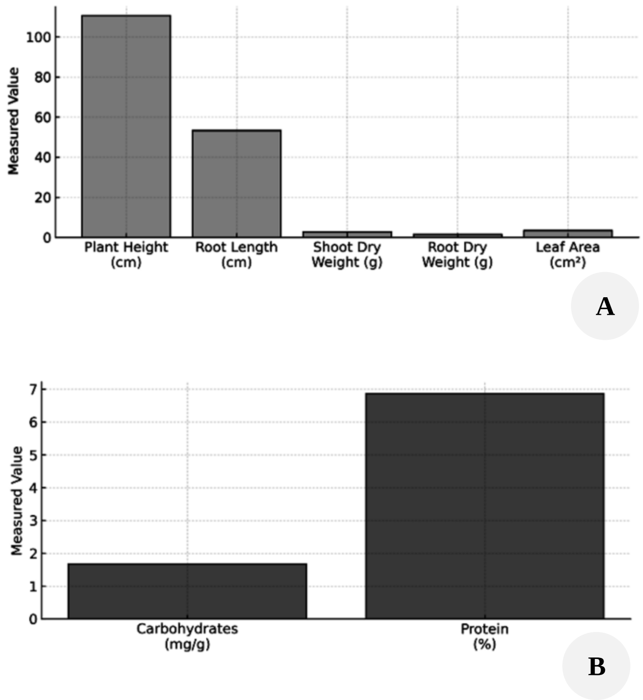

Figure 1. A. Morphological traits and B. Biochemical traits of tomato (*Solanum lycopersicum*) under optimal fertilization (0.250 kg/ha N + 0.150 kg/ha P). Values represent approximate optimal fertilization effects. Most traits peaked at N 0.250 × P 0.150, whereas shoot dry weight reached its maximum at N 0.200 × P 0.150

Table 3. Carbohydrate concentration (mg/g dry weight)

Nitrogen (kg/ha)	Phosphorus (kg/ha)	Carbohydrates (mg/g)
0.0	0.0	1.050 abc
0.180	0.0	1.622 a
0.200	0.0	1.648 a
0.250	0.0	1.389 a
0.0	0.120	1.424 ab
0.180	0.120	1.628 a
0.200	0.120	1.655 a
0.250	0.120	1.430 a
0.0	0.150	1.535 ab
0.180	0.150	1.634 a
0.200	0.150	1.667 a
0.250	0.150	1.465 a
0.0	0.200	1.615 a
0.180	0.200	1.641 a
0.200	0.200	1.533 ab
0.250	0.200	1.504 a

Note: Values are means. Different letters within a column indicate significant differences among treatments at ($p \leq 0.05$)

Table 4. Protein concentration (%)

Nitrogen (kg/ha)	Phosphorus (kg/ha)	Protein (%)
0.0	0.0	5.129 de
0.180	0.0	6.376 ab
0.200	0.0	6.491 ab
0.250	0.0	5.761 b
0.0	0.120	5.691 cd
0.180	0.120	6.416 ab
0.200	0.120	6.585 a
0.250	0.120	5.920 ab
0.0	0.150	5.830 bcd
0.180	0.150	6.459 ab
0.200	0.150	6.869 a
0.250	0.150	6.130 a
0.0	0.200	6.303 abc
0.180	0.200	6.473 ab
0.200	0.200	6.302 abc
0.250	0.200	6.112 a

Note: Values are means. Different letters within a column indicate significant differences among treatments at ($p \leq 0.05$)

Discussion

The research shows that combined nitrogen (N) and phosphorus (P) fertilization tended to enhance both morphological and biochemical attributes of tomato (*S. lycopersicum*) under controlled greenhouse conditions. The most pronounced improvements were observed when 0.250 kg/ha N and 0.150 kg/ha P were applied together, supporting the hypothesis that nutrient synergy produces greater benefits than single-nutrient application. This finding not only supports the principle of nutrient co-limitation but also highlights the potential for optimizing fertilizer regimes to achieve sustainable intensification in vegetable production systems. In arid and semi-arid regions, where nutrient availability and water resources are often limiting, targeted combinations of N and P can maximize physiological efficiency while minimizing environmental impact. Furthermore, integrating such fertilization strategies with improved irrigation methods, such as deficit irrigation or fertigation, may further enhance nutrient use efficiency and reduce losses to the environment (Naz et al. 2022).

Morphological responses and growth mechanisms

The marked increases in plant height, root length, and biomass under optimal fertilization are consistent with earlier findings on tomato and other horticultural crops (Kareem et al. 2020; Ronga et al. 2020). Although the absolute values of leaf area appeared low (3.24-3.46 cm^2), this outcome reflects the measurement method applied in the present study, where a digital planimeter was used on a representative single leaf per plant rather than the cumulative canopy. Accordingly, the data should be interpreted as relative indicators of treatment effects rather than absolute whole-plant leaf area. This approach remains valid for treatment comparisons, even though it underestimates the actual canopy size of tomato plants at 52 days after emergence. Nitrogen plays a key role in stimulating cell division and elongation through its involvement in chlorophyll biosynthesis, thereby enhancing photosynthetic capacity (Penuelas et al. 2023). Phosphorus, in turn, is crucial for ATP generation and root system development, improving nutrient and water uptake efficiency (Naz et al. 2022). The root development observed here—considerably longer than in controls—likely contributed to better anchorage, water absorption, and nutrient acquisition, which in turn supported shoot growth (Ronga et al. 2020; Naz et al. 2022). Plants that received high N but low P or vice versa showed only moderate growth because these macronutrient imbalances restricted their overall performance. The findings support the concept of "nutrient co-limitation" which states that insufficient amounts of one essential element restrict the advantages of another (Mishra et al. 2024) (Table 2).

Biochemical improvements and nutrient assimilation

The optimal N×P treatment led to increased carbohydrate content because it boosted photosynthetic rates while optimizing assimilate movement toward storage compounds. Research indicates that balanced N and P supply activates ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO) enzyme activity which drives carbon fixation in the Calvin cycle (Jin et al. 2023). The increase in protein concentration from 5.13% to 6.87% suggests improved nitrogen assimilation because of activated nitrate reductase and glutamine synthetase enzymes which drive amino acid and protein synthesis. The biosynthetic processes receive energy from adequate phosphorus availability through ATP which strengthens the synergistic relationship between these two nutrients. The research findings match previous studies about cereals and legumes because N and P co-application resulted in higher yields and increased grain protein content (Hasan et al. 2016; Ma et al. 2022). The identical response in tomato confirms that this nutrient interaction works across different plant species.

Environmental and agronomic implications

The research demonstrates that precision fertilization strategies need to balance nutrient ratios with environmental protection measures. The application of excessive N without sufficient P results in nitrate leaching that contaminates groundwater while excessive P without N balance leads to surface water eutrophication (Wang et al. 2021). The fertilizer rates identified in this study appear to balance plant growth with environmental considerations, suggesting their potential suitability for arid regions like Iraq.

The observed plant physiological improvements can be analyzed in relation to soil biodiversity. These interactions are schematically illustrated in Figure 2, which summarizes how nitrogen and phosphorus pathways synergistically enhance tomato growth and metabolism. The practice of balanced fertilization promotes beneficial microbial communities which lead to better nutrient cycling and improved soil health. The connection between nutrient management and microbial diversity presents a promising research direction for the region.

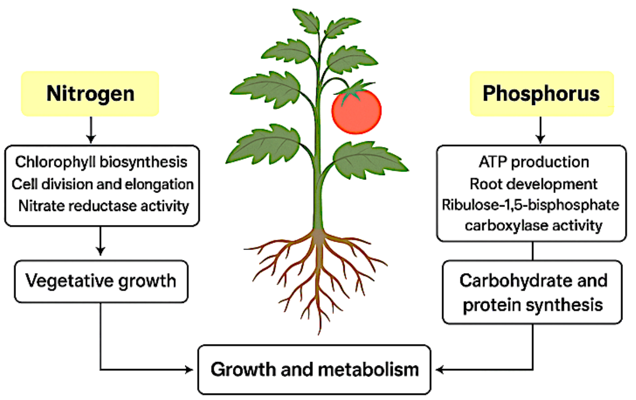

Figure 2. Schematic representation of nitrogen and phosphorus pathways enhancing growth and metabolism in tomato plants. This illustration was created by the author based on the study findings and supported by previous literature (e.g., Hasan et al. 2016; Jin et al. 2023)

Study limitations and future directions

The greenhouse environment provides controlled conditions yet it fails to replicate all the natural variations that occur in field farming. Future studies need to validate the results in open-field conditions where researchers can test the system under different temperature conditions and pest infestation levels and water availability. It may also be useful to extend the evaluation of N and P effects to additional biochemical markers—such as chlorophyll content and antioxidant activity—as well as to soil microbial biodiversity, which were not assessed in the present study. The extended trials will produce exact data about agricultural performance and sustainability results by uniting fertilization with water-saving irrigation systems. (Parasar and Agarwala 2025).

In conclusion, the research demonstrates that using nitrogen and phosphorus fertilizers together leads to better growth outcomes and nutritional enhancement of tomato plants. The elevated protein and carbohydrate levels show increased metabolic processes which demonstrate how these two macronutrients work together to develop plant structures and differentiate cells while accumulating nutrients in plant tissues. The dual fertilization approach supports better plant growth and yield potential while also contributing to the nutritional value of harvested crops which remains essential for public health and food security. The study supports the use of combined nitrogen and phosphorus as an effective nutrient management approach that may be beneficial for Iraqi agriculture because of its need for efficient practices due to climate challenges and soil fertility limitations.

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