

Potato (*Solanum tuberosum* L.) Response to Amino Acids Biostimulants Treatment under Organic Farming System

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Rapid population growth and escalating ecological challenges, including pollution and soil degradation exacerbated by climate change, pose significant threats to global agriculture. Plant biostimulants, particularly amino acid-based formulations, represent a promising, environmentally sustainable approach by reducing dependence on fertilizers and pesticides while enhancing crop yield potential. In this study, the effects of three biostimulant formulations on the yield and quality of 'Annabelle' potatoes cultivated under organic farming conditions with drip irrigation in western Slovakia were evaluated. The tested treatments consisted of amino acids alone, amino acids combined with magnesium, and amino acids combined with calcium and boron. Tuber yield and selected quality parameters, including dry matter, vitamin C, nitrate, starch, and reducing sugar contents, were assessed. Significant yield increases were observed across all treatments, with the combinations of amino acids with magnesium and with calcium and boron showing the most pronounced effects, resulting in up to a 38.65% increase in marketable yield compared with the control. Significant differences were also detected in vitamin C, nitrate, starch, and reducing sugar contents. These findings indicate the potential of amino acid-based biostimulants to enhance crop yield and quality under organic farming conditions.

Keywords: potatoes, marketable yield, biostimulants, amino acids, nutritional components

1 Introduction

As global development progresses and the world's population continues to increase, greater emphasis is being placed on improving crop quality alongside increasing yield. This situation represents a dual challenge: meeting rising agricultural demands while conserving natural resources, a concern acknowledged by both farmers and researchers (Baltazar et al., 2021; Wang et al., 2017). *Solanum tuberosum* L., commonly referred to as the potato, is recognized as the world's third most important food crop and plays a crucial role in the economies of many developing countries (Hill et al., 2021). Under stress-free conditions, potato yield is determined by canopy cover, radiation use efficiency, and the partitioning ratio of individual genotypes (Raja et al., 2020). Potatoes exhibit considerable phenotypic

diversity in terms of tuber shape, size, and nutritional composition and are widely acknowledged for their high nutritional value and their capacity to serve as carriers of health-promoting phytochemicals (Ramadan, 2016). Extensive research has been conducted to elucidate their carbohydrate, protein, mineral, and vitamin composition, thereby contributing substantially to the field of human nutrition (Ekin, 2011).

1.1 Plant Biostimulants in Organic Farming

Organic farming is regarded as an environmentally sustainable alternative to intensive agriculture, providing products with higher antioxidant levels and lower pesticide residues and nitrate contents compared with conventionally produced crops (Kazimierczak et al., 2019). However, the quality of organic production

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is strongly influenced by seasonal variability and appropriate cultivar selection (Ierna et al., 2022), while relatively low yields remain a significant challenge for farmers (Lombardo et al., 2020). In recent years, increasing attention has been directed toward the use of natural compounds to enhance crop productivity (Teixeira et al., 2017). Projected climate change impacts on crop growth and productivity have accelerated the development of innovative cultivation technologies. Among these approaches, plant biostimulants are considered environmentally sustainable tools with the potential to improve crop productivity and quality, particularly under adverse environmental conditions (Hill et al., 2021; Kocira, 2019; García-García et al., 2020; Baltazar et al., 2021). Their importance is further emphasized by the need to reduce reliance on conventional fertilizers and to adopt more sustainable agricultural practices (Alfosea-Simón et al., 2020; Zamljen et al., 2021; Dziugiel & Wadas, 2020), as reflected in the growing body of research focused on biostimulants (Gruszecki & Stawiarz, 2021). Plant biostimulants comprise a diverse group of substances that induce beneficial physiological responses in plants without acting as pesticides or conventional fertilizers (Rafiee et al., 2016; García-García et al., 2020; Sierras et al., 2015). These substances include amino acids, beneficial microorganisms, seaweed extracts, chitosan, phytohormones, plant growth regulators, and humic substances (Rafiee et al., 2016). Amino acid-based biostimulants, whose characteristics vary depending on their origin and manufacturing process, remain relatively underexplored despite their widespread use in crop production (Sierras et al., 2015; Teixeira et al., 2018; Baqir et al., 2019). Amino acids (AAs) play a fundamental role in plant metabolism, serving as precursors for protein synthesis, nitrogen assimilation and allocation, and signalling processes (Guo et al., 2021). A thorough understanding of their physiological effects is essential for the development of effective biostimulant formulations (Alfosea-Simón et al., 2021), as they have been shown to promote both vegetative and generative development, thereby enhancing crop yield and quality (Khan et al., 2019; Radkowski et al., 2021 a). Although positive effects of amino acids on plant growth have been widely reported, their efficacy may vary depending on environmental conditions, plant species, and application strategy (Gondek & Mierzwa-Hersztek, 2021). Exogenous application of amino acids has been shown to stimulate plant growth and improve quality parameters, potentially modifying root morphology and shoot architecture (Noroozlo et al., 2019 b; Guo et al., 2021), and thereby contributing to greater production stability, particularly under suboptimal growing conditions (Kocira et al., 2020).

2 Material and Methods

2.1 Establishment of the Experiment

The open field experiments were performed in the growing season 2020, within organic farming system of local farmer in Pusté Uľany (48.231631, 17.603109) as a part of experiments of Slovak University of Agriculture in Nitra, Institute of Horticulture. Soil parameters were assessed before the experiment. The experiment took place on soil characterized as chernozem with a granulometric composition classified as clayey-loamy, with a predominant presence of clay particles. The soil's particle distribution influences the risk of slaking, which can lead to pore clogging and soil structure degradation. Soil crumbling, or the mutual binding between soil particles, was suboptimal, suggesting a need for measures to enhance it. Given the risk of slaking, maintaining, or improving the soil organic matter (SOM) level was recommended, as organic matter facilitates binding between soil particles. Total N stock: 5,090 kg N ha⁻¹, Chemical C/N ratio 9, N-supplying capacity 100 kg N ha⁻¹, S-plant available 41 kg S ha⁻¹, P-plant available 0.9 kg P ha⁻¹, K-plant available 180 kg K ha⁻¹, Ca-plant available 465 kg Ca ha⁻¹, Organic matter 3.0%. During the experiment, granulated chicken manure (Biofer natur extra) was uniformly applied to the entire plot at a rate of 1.5 t ha⁻¹ based on the producer's recommendation.

2.2 Climatic Conditions at the Experimental Site

According to the global climate classification, Slovakia is situated within the northern temperate climate zone, characterized by a regular alternation of four seasons. The experimental site is classified as a very warm agroclimatic region within a very dry subregion. Meteorological data presented in Tables 1 and 2 describe the weather conditions prevailing at the experimental site during the growing season, including average precipitation and air temperature. These data were obtained from the nearest meteorological station located in the village of Kráľová pri Senci and operated by the Slovak Hydrometeorological Institute (SHMÚ, 2021). The recorded values were compared with the climatological normal for long-term period 1981–2010.

2.3 Experimental Variants and Characteristics of the Applied Biostimulants

For experimental purposes, a designated section within the cultivation field was established and divided into five experimental variants: a control variant without biostimulant application and four treatment variants (Table 3). A randomized block design (RBD) was used in the experiment. Tuber harvest from these variants was used to evaluate qualitative

Table 1 Evaluation of the mean monthly temperatures (t °C) in the selected months in 2020, according to climatology normal 1981–2010 in Kráľová pri Senci (SHMÚ, 2021)

Month	t (°C)	Long-term period 1981–2010	dT (°C)	Characteristic
II.	5.3	0.5	4.8	extra warm
III	6.0	4.8	1.2	warm
IV.	11.9	11.0	0.9	warm
V.	14.5	16.0	-1.5	cold
VI.	19.9	19.0	0.9	extra warm
VII.	21.2	22.1	0.9	extra warm

Table 2 Evaluation of the mean monthly total rainfalls (R mm) in the selected months in 2020, according to climatology normal 1981–2010 in Kráľová pri Senci (SHMÚ, 2021)

Month	t (°C)	Long-term period 1981–2010	dT (°C)	Characteristic
II.	42	33	+40	wet
III	52	30	+58	extra wet
IV.	3	33	-91	extra dry
V.	63	51	+24	normal
VI.	75	60	+25	normal
VII.	49	56	-12	dry

Table 3 Experimental variants

Variant	Tecamin Max application	Tecnokel Amino CaB application	Tecnokel Amino Mg application
	BBCH 35 – BBCH 39		
Control	–	–	–
T_{max}	3 L ha ⁻¹	–	–
T_{max} + TA CaB	3 L ha ⁻¹	3 L ha ⁻¹	–
T_{max} + TA Mg	3 L ha ⁻¹	–	0.8 L ha ⁻¹
TA Mg + TA CaB	–	3 L ha ⁻¹	0.8 L ha ⁻¹

BBCH 35–50% of plants meet between rows; BBCH 39 – crop cover complete: about 90% of plants meet between rows

and quantitative parameters. Each variant consisted of eight replicates. A single replicate corresponded to a 10 m-long section of a plant row with a width of 1 m. One untreated buffer row was maintained between adjacent variants to minimize potential cross-effects among treatments.

The following biostimulants were applied in accordance with the manufacturers' recommendations:

- Tecamin Max (T_{max}) – applied as a foliar spray at a rate of 3 L ha⁻¹, divided into three applications at two-week intervals. Composition: total amino acids 14.4%; free L-amino acids 12%; total nitrogen (N) 7%; phosphorus (P₂O₅) 1%; organic substances 60%; pH 6.6. (producer: Agritecno Fertilizantes, S.L.).
- Tecnokel Amino CaB (TA CaB) – applied as a foliar spray at a rate of 3 L ha⁻¹, divided into three applications at two-week intervals. Composition: free L-amino acids 6.0%; calcium (CaO) 13.30%

(199.1 g L⁻¹); boron (B) 0.20%; pH 3.8 (producer: Agritecno Fertilizantes, S.L.).

- Tecnokel Amino Mg (TA Mg) – applied as a foliar spray at a rate of 0.8 L ha⁻¹, divided into three applications at two-week intervals. Composition: free L-amino acids 6.0%; nitrogen (N) 6.0%; magnesium (MgO) 6.0%; pH 5.0 (producer: Agritecno Fertilizantes, S.L.).

Agricultural practices were applied uniformly across the entire cultivation plot. During the growing season, mechanical weed control was performed, and plant protection against pests and potato pathogens was implemented using biological preparations. Alginure is a biostimulant formulation that enhances plant resistance to fungal diseases. It contains seaweed extracts (*Ascophyllum nodosum*, *Laminaria* sp.), plant-derived amino acids, alginates, and phosphonates. Alginure was applied foliarly four times during the growing season at

14-day intervals. SpinTor is a natural insecticide based on spinosad (spinosyn A + spinosyn D), a compound produced through the fermentation activity of the bacterium *Saccharopolyspora spinosa*. SpinTor was applied foliarly four times during the growing season, triggered by the observed occurrence of *Leptinotarsa decemlineata*.

2.4 Plant Material

Early potatoes are very popular with consumers in Slovakia. Domestic production is not enough to meet demand, so they need to be imported. Potato of the variety 'Anabelle' was selected as the experimental crop based on recommendations for the organic market in the respective growing season. 'Anabelle' is an early-maturing, yellow-fleshed variety suitable for cultivation under organic farming systems. It produces balanced, oblong-oval tubers with cream-coloured skin, a high number of tubers per plant, and high yield potential. This variety is intended for direct consumption and is classified as cooking type A, with a recommended dry matter content of approximately 19%.

2.5 Marketable Yield Evaluation and Laboratory analyses

Potato tubers were planted on 18 April using a mechanized planter and were subsequently automatically hilled. Harvesting and yield assessment were performed manually on 27 July, at the end of the potato growing period, immediately prior to mechanized combine harvest. Manual harvesting was conducted to obtain accurate measurements and to prevent tuber damage. Each replicate within each variant was collected, weighed, and sorted according to the UNECE Standard FFV-52 for early potato varieties intended for marketing, allowing the proportion of marketable tubers to be determined. Total tuber yield and marketable yield were calculated from these data.

Refractometric dry matter content was measured using a CRUESS DR201-95 refractometer on homogenized potato samples from each replicate. Total dry matter content was determined gravimetrically by drying the potato samples in a laboratory oven at 105 °C until constant weight was achieved. Ascorbic acid content was quantified using high-performance liquid chromatography (HPLC) as described by Hegedúsová et al. (2015). Analysis was performed with a UV detector, employing an RP C18 column and a methanol-water mobile phase (5 : 95, v/v), with UV detection set at 258 nm. Starch content was determined using the polarimetric Ewers method, while reducing sugar content was assessed by Schoorl's titration method. Nitrate content in potato tubers was determined using

the potentiometric method with an ion-selective nitrate electrode.

2.6 Statistical Analysis

Statistical analyses were performed using Microsoft Excel 2010 (USA) and one-way analysis of variance (ANOVA) was conducted in Statgraphics Centurion XVIII (StatPoint Inc., USA). Significant differences between treatment means were evaluated using the least significant difference (LSD) test at a significance level of $P \leq 0.05$.

3 Results and Discussion

As indicated in Table 4, significant differences in total potato yield were observed among the experimental treatments. The TA Mg + TA CaB treatment had the greatest effect, resulting in an increase of 19.86 t ha⁻¹ ($P < 0.05$, 37.11%). The $T_{\max}$ variant also exhibited a significant yield increase of 18.25 t ha⁻¹ ($P < 0.05$, 33.64%). Combinations of $T_{\max}$ + TA Mg and $T_{\max}$ + TA CaB produced yield enhancements of 26.73% and 22.82%, respectively. One-way ANOVA revealed statistically significant differences between the control and all treatment groups.

Moreover, the application of biostimulants significantly increased marketable potato yield in most treatment variants, thereby elevating the proportion of marketable tubers. The observed differences between the control and treated variants suggest that the yield increase was achieved without compromising tuber quality in terms of size distribution or susceptibility to pest damage.

The application of amino acid-based biostimulants has been reported to enhance both the quantity and quality of crop yield, while also influencing plant biometric traits and chemical composition. These biostimulants have been proved to increase crop yield and leaf concentrations of essential nutrients, including potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), and zinc (Zn), as well as to mitigate losses caused by various pests (Wang et al., 2019; Noroozlo et al., 2019 a; Kocira et al., 2020). Amino acid biostimulants have also been associated with increased root development, biomass accumulation, improved stress tolerance, enhanced water use efficiency (Alfosea-Simón et al., 2020; Teixeira et al., 2021; Hayat et al., 2012), and elevated activity of enzymes such as phenylalanine ammonia-lyase (PAL) and catalase (Teixeira et al., 2017). Additionally, these compounds can serve as a potential source of nitrogen (Wang et al., 2019), representing an effective strategy for improving carbon fixation and photosynthetic nitrogen-use efficiency (Perchelík & Tegeder, 2018).

These findings are consistent with the results of the present study and are supported by numerous other

reports. For example, Kuznetsova et al. (2022) reported a significant increase in potato yield and quality, with a 13–16% rise in the proportion of marketable tubers. Similarly, Kumar et al. (2018) observed maximum tuber yield in potato plants treated with amino acids across two experimental years. Dziugiel and Wadas (2020) demonstrated that amino acid biostimulants enhanced yield under abiotic stress conditions, leading to improvements in marketable tuber productivity.

Table 5 shows that tuber dry matter content (TDM) was not significantly affected by the applied biostimulants, as determined by one-way ANOVA. During the study year, a trend toward an increase in TDM was observed following the application of the $T_{\max}$ + TA CaB treatment. The application of Tecamin Max alone resulted in the highest TDM increase of 7.98%. Comparable increases were recorded for the combination of $T_{\max}$ + TA Mg (3.87%, $P > 0.05$) and TA Mg + TA CaB (3.08%, $P > 0.05$). These treatments may have contributed to the enhancement of

tuber quality and storability. A marginal decrease in TDM of 1.03% ($P > 0.05$) was observed only in the $T_{\max}$ + TA CaB variant.

Refractometric dry matter content exhibited smaller changes compared with total dry matter. The $T_{\max}$ + TA Mg, TA Mg + TA CaB, and $T_{\max}$ + TA CaB variants showed an increase in total soluble solids ranging from 1.43% to 2.86%, whereas the $T_{\max}$ treatment alone resulted in a slight reduction of -0.61% in refractometric dry matter content.

Starch content, together with reducing sugar content and tuber dry matter, represent a key parameter influencing the quality and characteristics of harvested potato tubers. As shown in Table 6, the application of the tested amino acid-based preparations generally did not result in significant changes in starch content, with the exception of Tecamin Max, which induced a statistically significant increase of 21.45% ($P < 0.05$). Minor decreases in starch

Table 4 Average yield of potato tubers (t ha⁻¹) depending on the observed experimental variants

Variant	Total yield (t ha ⁻¹)	Difference (%)	Marketable yield (t ha ⁻¹)	Difference (%)
Control (C)	54.25 ±10.43 a	100.00	51.75 ±10.08 a	100.00
$T_{\max}$	72.50 ±7.69 b	133.64	69.13 ±6.29 b	133.58
$T_{\max}$ + TA Mg	68.75 ±10.97 ab	126.73	66.25 ±10.23 ab	128.02
TA Mg + TA CaB	74.38 ±8.52 b	137.11	71.75 ±9.08 b	138.65
$T_{\max}$ + TA CaB	66.63 ±14.07 ab	122.82	63.75 ±14.45 ab	123.19

average ±standard deviation; the different letters listed with the mean values in the columns represent statistically significant differences between the observed varieties ($P < 0.05$)

Table 5 Total dry matter (TDM) and refractometric dry matter (°Bx) content in potato tubers, depending on the observed experimental variants

Variant	TDM (%)	Difference (%)	Refractometric (°Bx)	Difference (%)
Control (C)	20.42 ±0.66 a	100.00	4.90 ±0.43 a	100.00
$T_{\max}$	22.05 ±0.08 a	107.98	4.87 ±0.54 a	99.39
$T_{\max}$ + TA Mg	21.21 ±1.16 a	103.87	5.02 ±0.53 a	102.45
TA Mg + TA CaB	21.05 ±0.66 a	103.08	4.97 ±0.67 a	101.43
$T_{\max}$ + TA CaB	20.21 ±1.25 a	98.97	5.04 ±0.54 a	102.86

average ±standard deviation; the different letters listed with the mean values in the columns represent statistically significant differences between the observed varieties ($P < 0.05$)

Table 6 Average values of starch (%) and reductive sugars (%) content in potato tubers, depending on the observed experimental variants

Variant	Starch content (%)	Difference (%)	Reductive sugars (%)	Difference (%)
Control (C)	12.89 ±0.06 a	100.00	1.41 ±0.01 b	100.00
$T_{\max}$	15.66 ±0.65 b	121.45	1.23 ±0.02 a	87.23
$T_{\max}$ + TA Mg	12.67 ±0.06 a	98.25	1.49 ±0.03 b	105.67
TA Mg + TA CaB	12.94 ±0.11 a	100.35	1.73 ±0.04 c	122.70
$T_{\max}$ + TA CaB	12.80 ±0.02 a	99.26	1.15 ±0.05 a	81.56

average ±standard deviation; the different letters listed with the mean values in the columns represent statistically significant differences between the observed varieties ($P < 0.05$)

Table 7 The ascorbic acid (AA) and nitrates content depending on the observed experimental variants

Variant	AA (mg 100 g ⁻¹)	Difference (%)	Nitrates (mg NO ₃ kg ⁻¹)	Difference (%)
Control (C)	11.75 ± 0.41 ab	100.00	87.68 ± 2.49 a	100.00
T _{max}	12.90 ± 2.04 b	109.79	95.02 ± 2.70 a	108.37
T _{max} + TA Mg	9.64 ± 0.39 a	82.04	77.86 ± 6.63 a	88.79
TA Mg + TA CaB	11.14 ± 0.02 ab	94.80	88.11 ± 12.47 a	100.49
T _{max} + TA CaB	12.45 ± 0.27 b	105.96	113.91 ± 6.46 b	129.92

average ± standard deviation; the different letters listed with the mean values in the columns represent statistically significant differences between the observed varieties ($P < 0.05$)

content were observed for the combinations of T_{max} + TA Mg (-1.75%) and T_{max} + TA CaB (-0.74%) compared with the control.

Regarding reducing sugar content, the application of amino acid-based treatments resulted in measurable changes among the variants (Table 6). Statistically significant differences were detected in three variants. The TA Mg + TA CaB treatment produced the largest increase in reducing sugars, amounting to 22.70% ($P < 0.05$). In contrast, the T_{max} variant (-12.77%, $P < 0.05$) and the T_{max} + TA CaB variant exhibited significant decreases in reducing sugar content, as determined by one-way ANOVA.

As shown in Table 7, the accumulation of ascorbic acid, a major antioxidant in potato tubers, varied among the experimental variants following amino acid application. No statistically significant differences were observed between the control and treated variants in terms of ascorbic acid content; however, notable differences were detected among the treatment variants. Specifically, the T_{max} and T_{max} + TA CaB treatments resulted in increases in ascorbic acid content of 9.79% and 5.96%, respectively. Conversely, decreases in ascorbic acid content were observed in the T_{max} + TA Mg (-17.96%) and TA Mg + TA CaB (-5.20%) variants. These results indicate that the effect of biostimulants on ascorbic acid content may depend on the specific treatment combinations and other influencing factors.

The experimental treatments also affected nitrate accumulation in tubers. Nitrate content increased slightly in the TA Mg + TA CaB (0.49%) and T_{max} (8.37%) variants, with a statistically significant increase observed in the T_{max} + TA CaB variant (29.92%). In contrast, the combination of T_{max} + TA Mg led to a decrease in nitrate content (-11.63%), reflecting a trend similar to that observed for ascorbic acid.

In horticultural crops, amino acid biostimulants have been shown to increase the content of bioactive substances in tomatoes (Alfosea-Simón et al., 2020) and to improve the quality of tomato seedlings (Alfosea-Simón et al., 2021). In chili, amino acid treatments significantly increased the production of metabolites, although their

effectiveness varied depending on cultivar and fruit part (Zamljen et al., 2021). Similarly, amino acids enhanced yield and quality of bell pepper plants under stress conditions (Betti et al., 1992).

Positive effects have also been reported in leafy and legume crops. Lettuce yield and quality were increased following amino acid application (Tsouvaltzis et al., 2014; Botta, 2013; Khan et al., 2019), suggesting that amino acids can serve as an effective partial substitute for conventional fertilizers. Foliar application of amino acid biostimulants improved soybean yield by 25% compared with the control, while phenolic and flavonoid contents increased by 34% and 74%, respectively (Kocira, 2019). Similar increases in soybean production were reported under greenhouse ($\geq 21\%$) and field ($\geq 22\%$) conditions (Teixeira et al., 2018, 2020). In beans, amino acid treatment increased yield, protein, and fiber content, as well as antioxidant potential, reflected in enhanced synthesis of phenolics, flavonoids, and anthocyanins (Gruszecki & Stawiarz, 2021).

In cereals, amino acid treatments increased winter wheat grain yield by 5.4% and 11% compared with untreated controls (Popko et al., 2018). Maize root biomass was reported to increase by 100% following amino acid application (Matysiak et al., 2020). In addition, silage produced from plants treated with amino acid biostimulants contained significantly higher total protein in dry matter, whereas crude fiber content changed only slightly; lactic acid content was also higher, indicating improved silage quality (Radkowski et al., 2021 b).

4 Conclusions

Despite the increasing interest in biostimulants and the expanding body of knowledge on their use, their variable efficacy remains incompletely understood in many cases. The present study confirms that biostimulants, particularly those based on amino acids, exert a significant influence on potato tuber yield under organic farming conditions. Although all tested variants led to increases in potato yield, their effects on specific nutritional parameters, such as vitamin C content and nitrate accumulation, were variable. These

findings indicate that the effectiveness of amino acid-based biostimulants in early potato cultivation is not determined solely by the biostimulant itself but may also depend on interactions among the applied compounds. Notably, the application of a biostimulant containing 12% free L-amino acids, without additional micronutrients, produced the most pronounced effects on harvest quality, significantly enhancing vitamin C content, starch content, and gravimetric dry matter, while resulting in a statistically significant 33.64% increase in total tuber yield.

Overall, the evaluated amino acid-based biostimulants demonstrated the potential to substantially improve yield in organic potato production while generally maintaining or minimally altering tuber quality. However, the observed effects may vary depending on factors such as crop type, cultivar, and local soil and climatic conditions. Therefore, further research is warranted to achieve a more comprehensive understanding of their efficacy and to optimize their application under diverse agricultural conditions.

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