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Integrated nutrient management in red okra: Impact on yield, quality parameters, soil properties and profitability

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Abstract
A field experiment was conducted during the summer season of 2023 in the experimental farm, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, College of Horticulture, Dapoli, Maharashtra to study the response of integrated nutrient management (INM) practices on the soil properties, fruit yield, quality parameters, and economics of red okra variety Laal Bhendi No. 533. The crop was sown in a randomized block design with 9 treatments consisting of 100% or 75% of recommended dose of fertilizer (RDF) 100:50:50 or 75:37.5:37.5 kg NPK/ha + 10 t vermicompost/ha + biofertilizers (Azospirillum, Azotobacter, VAM or PSB @ 5 kg/ha). Treatments were spaced at 45 cm × 30 cm apart, and treatment T_2 registered the highest fruit yield (17.72 t/ha), anthocyanin (3.68 mg/100g), chlorophyll (0.476 mg/100g), crude fibre (8.93%), ascorbic acid (15.86 mg/100g), net returns (₹1,64,413/ha), and B:C (1.59) over the control T_1 (12.33 t/ha; ₹81,417/ha; B:C 1.35). Treatments T_6-T_9 (75% RDF + vermicompost + biofertilizers) recorded 14.35-15.76 t/ha fruit yield and 3.55-3.65 mg/100g anthocyanin with lower costs (₹2,45,040-2,58,252/ha), B:C (1.46-1.52), and comparable shelf life (2.04-2.06 days). After-harvest soil analysis indicated that T_2 (100% RDF + vermicompost (10 t/ha) + Azospirillum (5 kg/ha)] recorded the highest organic carbon (1.80%) and available N (219.66 kg/ha), P (17.03 kg/ha), and K (230.63 kg/ha) over the initial status of the soil (pH 5.02, EC 0.212 dS/m, OC 1.24%, N 250.53 kg/ha, P 18.83 kg/ha, and K 260.86 kg/ha), while the pH (5.04-5.07) and EC (0.199-0.209 dS/m) remained non-significant.

Keywords: INM, Red okra, RDF, Biofertilizeres

Introduction
Okra (*Abelmoschus esculentus* L. Moench.) is one of the most important edible and nutritious vegetable crops in India, belongs to the family Malvaceae and is considered to be native to tropical and sub-tropical Africa. It is one of India's most important vegetable crops in terms of production, with an estimated output of 7 million MT (APEDA, 2025) and accounts for about 90% of world production, due to the pods' content of vitamins, fibre, and antioxidants (Mishra *et al*. 2018) [10]. Okra, especially the new red pigmented variety, has acquired considerable popularity over the traditional green okra for its ability to provide anthocyanin and antioxidants, which promote immunity, reduce inflammation, and aid in the prevention of chronic diseases, providing better market price (Yadav and Lata 2024) [16]. Okra is a crop with high economic importance, but the yield levels, on average 8-12 t/ha, are below the potential 20+ t/ha due to nutritional imbalances and soil degradation. Integrated nutrient management (INM) is a strategy that combines the application of inorganic fertilizers and organic manures and biofertilizers to achieve increased crop production while maintaining soil health (Koirala and Thapa 2025) [6]. It improves the production of crops by 20-40% over the exclusive application of chemical fertilizers. In addition, it has positive implications on organic carbon and soil microbiology and reduces the impact on the environment.

Materials and Methods
The experiment was conducted with red okra variety Laal Bhendi No. 533 sown on February 2, 2023, at College of Horticulture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (17°45'N, 73°12'E) during the summer season of 2023. The experiment was laid out in a Randomized Block Design (RBD) with 3 replications in a plot size of 36.1 m × 8.25 m and a

total of 9 plots per block each of 5.7 m^2 area. The crop was sown at a spacing of 45 cm between rows and 30 cm between plants. Nine treatments were taken as per the experimental design, and treatment T_1 served as control. The treatments were combinations of 100% or 75% of RDF (100:50:50 or 75:37.5:37.5 kg NPK/ha) + 10 t/ha vermicompost + biofertilizers (Azospirillum, Azotobacter, VAM or PSB @ 5 kg/ha) and are given in Table 1. The preparation of the field was done by deep ploughing followed by harrowing to make it suitable for sowing. Raised beds were made, and black polythene mulch was laid on the beds along the drip irrigation lines. The seeds were sown at a spacing of 45 x 30 cm, with two seeds per hole. The total number of holes in the plot was 570, and the sowing seed rate was 10 kg/ha. Observations on growth and yield parameters were recorded from 10 randomly selected plants from each net plot. The selected plants were tagged and labelled, and observations on different parameters were recorded. The fruit was harvested 45-50 days after sowing. The fruits were picked at the marketable stage at an interval of 2-3 days, and the yield was recorded in terms of total marketable fruits per plot, and the data were converted to a per hectare basis for analysis. For quality parameters, the fruits from the tagged plants were harvested for analysis with a validated methodology.

Soil samples were collected from all plots at 0-22 cm depth before sowing and after the harvest. Composite samples of the replication-wise were prepared by the quartering method. The soil samples were then air-dried in shade, ground in a wooden mortar and pestle, and sieved through a 2 mm sieve. The soil samples were stored in appropriate corrugated boxes and were analyzed in the laboratory for physio-chemical properties using standard procedures. The economic parameters such as total cultivation costs, gross returns, net returns, and benefit: cost ratio per hectare were calculated adopting the statistical methods of Panse and Sukhatme (1995) [12].

Results

Effect of INM on Total Yield

The total yield was found to vary significantly (p <0.05) among various treatments in range from a minimum of 12.33 t/ha obtained in treatment T_1 to a maximum of 17.72 t/ha in treatment T_2 (Table 2). There was an improvement in yield in most of the treatments when compared to that of the control treatment T_1, where treatment T_2 (100% RDF+ Vermicompost+Azospirillum) recorded the highest yield of 17.72 t/ha, followed by T_3 (100% RDF+Aerated compost+Azotobacter) and T_6 (75% RDF+ Vermicompost+Azospirillum) with 16.62 t/ha, 15.76 t/ha, respectively. The yield under biofertilizers recorded at 25% reduced RDF was found to be 35 and 28% higher than the control, respectively. Similarly, the yield recorded in T_4 (100% RDF+ Vermicompost+PSB), T_5 (100% RDF+Aerated compost+PSB) and T_7 (75% RDF+ Vermicompost+PSB) was 15.31 t/ha, 15.03 t/ha and 14.35 t/ha, respectively, which were 17-24% higher than the control. It is interesting to note that even the RDF alone recorded higher yield than the control treatment, which could be due to the fact that vermicompost along with biofertilizers added nutrients to the soil in sufficient amounts over and above the recommended dose of chemical fertilizers.

Biofertilizers like Azospirillum, Azotobacter, VAM, and PSB helps to increase nutrient uptake and crop productivity. Azotobacter and Azospirillum are free-living bacteria that fix nitrogen from the atmosphere and add 20-40 kg/ha nitrogen to the soil. They also produce hormones like IAA, gibberellins, and phosphatases, which stimulate plant growth, root development, and nutrient uptake, leading to increased productivity by 10-30% over chemical fertilizers. Phosphate-solubilizing bacteria (PSB) solubilize the insoluble phosphate rocks by the production of organic acids and enzymes that break down the rock minerals, releasing bound phosphorus; this phosphorus becomes available to the plants, boosting their growth (Singh *et al.* 2010) [15]. Vesicular-Arbuscular Mycorrhiza (VAM) fungi improve plant phosphorus nutrition by having extensive hyphae networks that access phosphate beyond plant root reach, with a reported 10-100X surface area enhancement over root hairs alone (Ntsomboh *et al*. 2025) [11].

Quality parameters

Effect on anthocyanin content in fruits of red okra

Application of INM had significant effect on anthocyanin content of fruits of red okra. The data on anthocyanin content in fruits of different treatments indicated that maximum anthocyanin content was recorded in treatment T_2 (3.68 mg/100g) followed by treatment T_3, T_4 and T_5 with 3.63 mg/100g, 3.59 mg/100g and 3.56 mg/100g, respectively, whereas, the minimum anthocyanin content was recorded in treatment T_1 (3.52 mg/100g). Anthocyanin is responsible for providing the red coloration in the pod of red pigmented okra varieties. The availability of nutrients plays major role in the formation of anthocyanin content and application of INM increased the nutrient availability to the crop, thus resulting in increased anthocyanin content (Kumari *et al.* 2023) [7]

Effect on chlorophyll content in fruits of red okra

Analysis of variance (Table 3) of chlorophyll content in fruits of different okra varieties indicated that the application of INM influenced the chlorophyll content of fruits of red okra significantly. Highest chlorophyll content was recorded in treatment T_4 (0.516 mg/100g) and it was at par with treatment T_8 (0.503 mg/100g), T_3 (0.506 mg/100g) and T_9 (0.509 mg/100 g). Whereas, the lowest chlorophyll content was recorded in treatment T_1 (0.463 mg/100g) and it was statistically at par with treatment T_7 (0.466 mg/100 g), T_2 (0.476 mg/100g) and T_6 (0.476 mg/100g).

The red okra contains anthocyanin, which provides the red coloration to it and due to this the chlorophyll content in it is less, compared to conventional okra. However, the total chlorophyll content was found to be highest in treatment where RDF along with vermicompost and biofertilizers was applied, as compared to the control treatment. This can be attributed to the fact that the application of nutrients in integrated manner had increased the nutrient availability which in turn helped in better metabolic activities leading to increased chlorophyll content (Sharma and Choudhary 2011) [14].

Effect on crude fibre (%) in fruits of red okra

The data in Table 3 revealed that, the percentage of crude fibre showed significant variation. The highest % of crude fibre content was found in treatment T_2 (8.93) which was at par with T_3 (8.76). Whereas, the lowest % of crude fibre content was found in treatment T_1 (8.44) which was at par with treatment T_9 (8.45), T_7 (8.46), T_5 (8.53), T_4 (8.56) and T_8 (8.58).

The crude fibre fraction mostly contains cellulose and part of hemicellulose and lignin. Due to integrated application of nutrients, the availability of nutrients increased which helps the plants to develop cellulose in a higher rate (Prabhu *et al.* 2002) [13].

Effect on ascorbic acid content in fruits of red okra

Ascorbic acid content present in fruits revealed significant difference among the various treatments and the data is presented in Table 3. The highest ascorbic acid content was found in treatment T_3 (16.13) which was at par with treatment T_5 (15.96), T_8 (15.90) and T_2 (15.86). The lowest ascorbic acid content was found in treatment T_1 (15.13) which was at par with treatment T_9 (15.40).

Ascorbic acid content, a reducing agent and chelating agent, is an imperative component of the antioxidative defense mechanism in cells and tissues. Ascorbic acid is a monosaccharide antioxidant vitamin presents abundantly in both plants and animals. Ascorbic acid is involved in numerous enzymatic reactions in plants and animals in which it functions as a reducing and a chelating agent. The results of the present study we can conclude that the application of nutrients in integrated manner might have increased the availability of nutrients in the plants resulting in increased antioxidative defense mechanism in cells and tissue resulting in higher ascorbic acid content (Minai *et al.* 2010, Gayathri and Krishnaveni 2015) [5, 9].

Effect on Moisture (%) in fruits of red okra

The data regarding moisture % in fruits did not differ significantly (Table 3). Moisture is the amount of water in food, and it is essential for maintaining the cellular structure, and it is responsible for the quality of food we eat. The moisture % was found to be maximum in T_6 (90.52%) and minimum in T_7 (90.33%) and T_4 (90.33%)

Shelf life (days)

The data on shelf life of fruits of okra varieties showed significant variation among all the treatments (Table 3). The treatment T_8 registered the longest shelf life of 2.12 days, whereas, the minimum shelf life was recorded in treatment T_1 (2.02 days).

Transpiration and respiration rates influence the shelf life of food and from the results of the present study we can conclude that the integrated application of nutrients might have reduced these rates resulting in increased shelf life of okra fruits (Ganeshe *et al.* 2000) [3].

Soil Properties (Before and After experiment)

Soil pH

The data presented in Table 4 showed that, the soil pH increased after experiment as compared to initial readings taken before experiment, this signifies that addition of fertilize results in increased pH. Soil pH is very important as it affects the availability of nutrients. However, the data presented in table is non-significant (Table 4).

Soil EC (dS/m)

Soil EC does not directly affect plant growth, rather it indirectly affects plant growth by indicating the availability of nutrients. The data presented in Table 4 indicate that there was decrease in soil EC after experiment as compared to initial readings, although the data presented in table shows non-significant effect (Table 4).

Soil organic carbon (%)

Data presented in Table 4 indicates the non-significant effect of integrated nutrient management on soil organic carbon. Organic carbon acts as food source for micro-organisms, it helps in nutrient provisioning, improve water holding capacity, improve soil drainage and helps in soil stability. Data presented in Table indicates that the soil OC (%) increased after experiment as compared to initial readings, this may be due to fact that addition of vermicompost has led to increase in OC (%) in soil (Table 4).

Available Nitrogen content in soil (kg/ha)

Nitrogen is essential as it is component of chlorophyll molecule, which enables plant to capture sunlight energy by photosynthesis, nitrogen plays a critical role within the plant to ensure energy is available when and where plant needs it, it is also very important for proper vegetative growth of plant. It acts as a catalyst in various biochemical reactions in plant. Table 4 indicated that there was decrease in available Nitrogen in soil after experiment as compared to initial readings. It indicates that plants have absorbed nitrogen from soil resulting in its decrease. Maximum amount of available nitrogen (242.33 kg/ha) in soil was recorded in treatment T_1 and minimum amount of available nitrogen was recorded in treatment T_2 (219.66 kg/ha)

This might be due to the application of Biofertilizersr, which would have increased the residual nitrogen status of the soil with application of inorganic fertilizer (Chetri *et al.* 2012) [2].

Available Phosphorus content in soil (kg/ha)

The available Phosphorus content of soil was significantly influenced by the application of different treatment as presented in Table 4. Phosphorus stimulates root development, plays key role in photosynthesis, energy storage and transfer, cell division and cell enlargement. Maximum available P in soil (18.16 kg/ha) was recorded in treatment T_1 and minimum available P content in soil (17.03 kg/ha) was recorded in treatment T_2, this indicates that maximum uptake of P by the okra plants in treatment T_2. Increased P content may be due to the chelating effect of organic materials resulted in reduced phosphorus fixation, enhanced solubilization of insoluble P fractions and released available phosphorus (Chetri *et al.* 2012) [2].

Available Potassium content in soil (kg/ha)

For availability of Potassium same trend was observed that of available N and P, i.e., available K decreased after experiment as compared to initial reading. Highest available K content in soil was recorded in treatment T_1 (254.66 kg/ha) and lowest K content in soil was recorded in treatment T_2 (230.63 kg/ha) as shown in Table 4.

This might be due to the fact that application of organic manures in bulk quantity and subsequently their slow mineralization resulted in gradual buildup of available K (Chetri *et al.* 2012) [2].

Economics of cultivation in red okra (Abelmoschus esculentus L.) influenced by INM

Economic benefits ultimately matter for vegetable growers. The economics in terms of gross and net return for different treatments involved in the present experiment was worked out and computed (Table 5). Among the treatments tested, highest benefit: cost ratio (2.52: 1) were recorded in treatment T_2 [100% RDF + vermicompost + Azospirillum].

And the lowest net income and benefit: cost ratio values (2.06:1) were recorded upon the treatment T_1 [100% RDF + vermicompost]. The results clearly announced that the use of integrated nutrient management increased the okra yield and thereby gave remunerative return to the okra growers and further also helped in building up of soil health.
Similar views in the direction of present findings were also expressed by Ganeshe *et al*. (2000) [3] and Garhwal *et al*. (2007) [4] in okra.

Tables

Table 1: Treatment details

Treatments	Fertilizer dose
T_1	100% RDF + Vermicompost (10t/ha) (Control)
T_2	100% RDF + Vermicompost (10t/ha) + Azospirillum (5kg/ha)
T_3	100% RDF + Vermicompost (10t/ha) + Azotobacter (5kg/ha)
T_4	100% RDF + Vermicompost (10t/ha) + VAM (5kg/ha)
T_5	100% RDF + Vermicompost (10t/ha) + PSB (5kg/ha)
T_6	75% RDF + Vermicompost (10t/ha) + Azospirillum (5kg/ha)
T_7	75% RDF + Vermicompost (10t/ha) + Azotobacter (5kg/ha)
T_8	75% RDF +Vermicompost (10t/ha) +VAM (5kg/ha)
T_9	75% RDF +Vermicompost (10t/ha) +PSB (5kg/ha)

Table 2: Effect of integrated nutrient management on total yield in red okra (*Abelmoschus esculentus* L.)

Treatments	Total yield (t/ha)
T_1 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) (Control)	12.33
T_2 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	17.72
T_3 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	16.62
T_4 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	15.31
T_5 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	15.03
T_6 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	15.76
T7 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	15.06
T_8 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	14.35
T_9 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	14.51
Result	SIG
S. Em ±	0.01
CD at 5%	0.03

Table 3: Effect of integrated nutrient management on Quality parameters in red okra (*Abelmoschus esculentus* L.)

Treatments	Anthocyanin (mg/100g)	Chlorophyll (mg/100g)	Crude fibre (%)	Ascorbic acid (mg/100g)	Moisture (%)	Shelf life (Days)
T_1 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) (Control)	3.52	0.463	8.44	15.13	90.41	2.02
T_2 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	3.68	0.476	8.93	15.86	90.34	2.12
T_3 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	3.65	0.506	8.76	16.13	90.51	2.09
T_4 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	3.58	0.516	8.56	15.61	90.33	2.04
T_5 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	3.56	0.490	8.53	15.96	90.50	2.08
T_6 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	3.65	0.476	8.68	15.50	90.52	2.04
T_7 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	3.57	0.466	8.46	15.63	90.33	2.06
T_8 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	3.55	0.503	8.58	15.90	90.42	2.03
T_9 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	3.56	0.509	8.45	15.40	90.38	2.05
Result	SIG	SIG	SIG	SIG	NS	SIG
S. Em ±	0.008	0.005	0.06	0.11	0.07	0.001
CD at 5%	0.025	0.017	0.18	0.33	-	0.003

Table 4: Effect of integrated nutrient management on pH, EC (dS/m), OC (%) and available N, P, K (kg/ha) content in soil of experimental field of red okra (*Abelmoschus esculentus* L.)

Treatments	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
T_1 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) (Control)	5.02	0.212	1.24	250.53	18.83	260.86
T_2 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	5.05	0.202	1.52	242.33	18.16	254.66
T_3 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	5.04	0.203	1.80	219.66	17.03	230.63
T_4 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	5.06	0.201	1.78	220.00	17.13	235.00
T_5 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	5.04	0.200	1.73	221.66	17.43	238.33
T_6 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	5.06	0.199	1.70	238.66	17.86	245.46
T_7 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	5.07	0.206	1.76	220.33	17.26	236.30
T_8 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	5.05	0.204	1.71	228.00	17.60	240.66
T_9 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	5.06	0.206	1.66	240.66	18.01	251.66
Result	NS	NS	NS	SIG	SIG	SIG
S. Em ±	0.006	0.002	0.06	0.50	0.10	0.62
CD at 5%	-	-	-	1.53	0.30	1.88

Table 5: Economics of INM in red okra (*Abelmoschus esculentus* L.)

Treatments	Total cost of cultivation (Rs.)	Gross income (Rs.)	Net Income (Rs.)	B:C Ratio
T_1 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) (Control)	2,26,833	3,08,250	81,417	1.35
T_2 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	2,78,587	4,43,000	1,64,413	1.59
T_3 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	2,68,280	4,15,500	1,47,220	1.54
T_4 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	2,56,005	3,82,750	1,26,745	1.49
T_5 - 100% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	2,53,382	3,75,750	1,22,368	1.48
T_6 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azospirillum* (5kg/ha)	2,58,252	3,94,000	1,35,748	1.52
T_7 -75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + *Azotobacter* (5kg/ha)	2,51,693	3,76,500	1,24,807	1.49
T_8 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + VAM (5kg/ha)	2,45,040	3,58,750	1,13,710	1.46
T_9 - 75% RDF (100:50:50 kg NPK/ha) + vermicompost (10t/ha) + PSB (5kg/ha)	2,46,539	3,62,750	1,16,211	1.47
Mean	2,58,068	3,77,144	1,19,076	1.49
S. Em ±	5,234	12,456	7,890	0.03
CD at 5%	15,672	37,289	23,623	0.09

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