Yogur bajo en calorías añadido con harina de yacón: desarrollo y evaluación físico-química

Low-calorie yogurt added with yacon flour: development and physicochemical evaluation

ABSTRACT

Yacon flour has been used in several food products due to its high fructooligosaccharides and inulin contents, compounds that present health promoting properties. In this study, yacon flour was used as an ingredient in light yogurt in the following concentrations: 1.58; 2.56; 3.00 and 3.86%. Centesimal composition, pH, soluble solids, acidity and apparent viscosity of the yogurt supplemented with yacon were determined. Results were evaluated through analyses of variance and regression. Centesimal composition of the yogurts allowed for their classification as low-fat foods, presenting low carbohydrate content and containing dietary fiber, especially those supplemented with more than 2.56% yacon flour, which may be considered as sources of fiber and, consequently, prebiotics. Physicochemical analysis revealed significant ($p < 0.05$) changes in analysis of color, soluble solids, acidity and viscosity at the temperatures of 10 and 25 °C with the increase in yacon flour.

Key words: fructooligosaccharides, inulin, prebiotics, yogurt, yacon.

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INTRODUCTION

A growing concern regarding health and quality of life is causing people to value physical exercise, eating healthier foods and reducing consumption of those high in sugar, salt and fat. The main cause for this change in lifestyle and eating habits is a constant search for health, which assures a better quality of life and prevents diseases (1).

Parallel to this, there has been a rapid development in foods which present not only nutritional characteristics and proper technology, but also ingredients that have a biological role in preventing diseases and promoting health, known as functional foods (2).

Among functional food, one group that can be highlighted is prebiotics, which are non-digestible components, usually oligosaccharides, with bifidogenic effects capable of stimulating growth and/or the activity of some of the bacteria present in the intestine (3).

Yacon (*Smallanthus sonchifolius*, *Polymnia sonchifolia* Poepp. & Endl. or *Polymnia edulis* Wedd – 4) is a root found in the Andean region known for its high concentration of fructooligosaccharides (FOS), a special kind of carbohydrate with beneficial attributes to human health. One of the main characteristics of such carbohydrates is their ability to stimulate the growth of non-pathogenic bacteria through colonic fermentation, which causes them to be classified as bioactive

components with claimed prebiotic effects (5), and consequently, functional foods.

Because of the nutritional benefits presented by yacon, its flour has been developed and used as an ingredient in some foods. This allows scientists to formulate products with low fat content, low caloric value and a high concentration of dietary fiber, especially FOS, which may provide a protective effect to customer health (6).

In Brazil, the addition of yacon flour is reported mainly as an ingredient in cereal-based products, such as cakes, "Champurrada" type biscuits, snacks and breads (6, 7). No application of this product is found whatsoever in drinks, since milk-based products are easily consumed and versatile with high physiological functionality, and also viewed as healthy products among consumers.

Development of light yogurt supplemented with yacon flour may be a good alternative in the fermented food market, allowing the preparation of a drink with prebiotic claims due to its high soluble dietary fiber content (especially FOS) for aiding in the functioning the intestinal tract, regardless of consumer age. The product may also contribute to reduce toxic metabolites and plasmatic cholesterol, improve mineral bioavailability, such as calcium, magnesium and phosphorus, contribute to the growth of bifidobacterium inside the colon, and also help in reduction of blood pressure (8).

Based on these facts, the objective of the present study was to use different proportions of yacon flour as an ingredient in the preparation of light yogurts followed by evaluation of its effect on the physicochemical properties of the product.

MATERIAL AND METHODS

Experimental planning

Preparation of yogurts was conducted according to a completely randomized design, with four formulations and one control, in two repetitions. Four different concentrations of yacon flour were added to the yogurt prepared from skim milk and sweetened with aspartame (0.072 %). The yacon flour concentration was estimated according to the quantity of dietary fiber, FOS and/or inulin recommended by the ANVISA (National Agency for Sanitary Surveillance) (9) for liquid food with claims of functional properties. This estimate was based on yacon flour centesimal composition. Thus, yacon flour was added to the yogurts at concentrations of 1.58, 2.56, 3.00 and 3.86%. These values are calculated to provide 1.50 g total fiber; 1.50 g of FOS and inulin; 1.75 g of FOS and inulin; and 1.50 g FOS per serving of yogurt, respectively. The yogurt serving size was set to be 200 mL. The control yogurt consisted of a basic mixture of skim milk sweetened with aspartame, without addition of yacon flour.

Production of yacon flour

Yacon flour was produced according to the methodology described in Ribeiro (10), being obtained from 45.5 kg of yacon roots "in nature" which were purchased at the Belo Horizonte, MG vegetable market, between August and September 2009. The roots were manually peeled, sliced in a Walita RI7625 food processor and submersed, first, for 15 minutes in stainless steel bowls containing a sodium hypochlorite solution (4 to 6 % active chlorine) at 200 µL/L, and then into another stainless steel bowl containing a sodium bisulfite solution at 0.1% of the peeled root weight. Later, the sliced roots were dried in forced air ovens (Nova Ética 400ND/300 °C, Vargem Grande Paulista, Brasil) at 55 °C for 48 h. The sliced dried roots were then ground in a vertical rotor fixed hammer mill (Marconi MA-090/CF, Piracicaba, Brasil) to obtain the flour, which was packed into polyethylene sacks and stored at 2 – 4 °C.

Process for production of light yogurt added with yacon

Yacon flour and aspartame were added to skim milk and mixing was performed in a shaker (Omni Macro ES Digital Programmable Homogenizer, Kennesaw, USA) at 4,480 x g for 10 min and then heated to 83 °C and maintained at this temperature for 30 min inside a 20 L stainless steel yoghurt maker (Biasinox, Lambari, Brasil). This mixture was then cooled to 42 °C and supplemented with 0.02 % concentrated freeze-dried, DVS type lactic acid bacteria containing *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* (Christian Hansen, Valinhos, Brasil).

Milk fermentation occurred for about 6 h at 42 – 43 °C until the yogurt reached acidity values of 0.70 – 0.75 % (in % of lactic acid). The yogurt was then cooled to 37 °C, submitted to curd breaking and then immediately packed in 860 mL polyethylene packages. The packages were stored at 2 – 4 °C until the time of analysis, for a total of 30 days. Each yogurt formulation, control and the four different levels of yacon flour, was produced in two separate runs (replication).

Determination of the centesimal composition of the yogurts

The following analyses were performed: water content, via the gravimetric analysis (method 935.29 of AOAC, 11); protein, via the micro-Kjeldahl method (method 991.20 of AOAC, 11); lipids, via direct extraction in Soxhlet (method 963.15 of AOAC, 11) and ash via incineration (method 923.03 of AOAC, 11). Total dietary fiber (TDF) content was determined by summing soluble dietary fiber (SDF), insoluble dietary fiber (IDF), FOS and inulin contents. All measurements were made in duplicate.

The SDF and IDF contents were determined using a total dietary fiber assay kit from Sigma®, according to techniques established by the AOAC (12), which are based on enzymatic-gravimetric analyses. Results were reported as the average of duplicates for each experimental yogurt unit.

Determination of FOS and inulin were carried out according to the method reported by Kaneko et al. (13) using high performance liquid chromatography (HPLC) with the HPX 87P column from BIO-RAD (lead stationary phase) (California, USA), with purified water as the mobile phase. Samples were injected into the HPX 87P column coupled to a Pro-Star 410 liquid chromatograph from Varian with refraction index detector and an automatic injector (Auto Samples 410), with a flow rate of 0.6 mL/min and column temperature of 85 °C, projecting a sequence of peaks that were compared to the standards.

The carbohydrate fraction was determined to be the remaining portion of the sample after discounting the levels of water, protein, lipid, ash and total dietary fiber.

Determination of the caloric value of the yogurts

The caloric value of the yogurt was calculated by using the Atwater coefficients, which consider 4 kcal/g for proteins and carbohydrates and 9 kcal/g for lipids (14).

Determination of Lab color values of the yogurts

Lab color coordinates were determined by a CR-10 color reader from Konica Minolta with the following operating conditions: CIE D65 illuminator (natural daylight), set at an angle of 8° and a CIE 10° standard observer. The colorimeter directly supplied the L* (luminosity), a* and b* color values. The parameter a* takes positive values for reddish colors and negative values for the greenish ones, whereas b* takes positive values for yellowish colors and negative values for the bluish ones (15).

The calculation was obtained from two readings for each run, with the yogurt sample being put inside a 4 mL polystyrene cuvette, and between readings the cuvettes were washed with distilled water.

Determination of pH of the yogurts

The determination of pH was made according to the 017/IV method described by the Adolfo Lutz Institute (16) through direct reading with a digital pH meter (Tekna T-1000, São Bernardo do Campo, Brasil) using a 10 mL yogurt sample from each experimental unit.

Determination of total soluble solids

Total soluble solid values were measured directly in a bench-top ABBE refractometer (São Paulo, Brasil) at temperature of 20 ± 3 °C, with results given in °Brix according to the analytical rules of the Adolfo Lutz Institute (16).

Determination of acidity of the yogurts

The acidity was measured according to the 427/IV method described by the Adolfo Lutz Institute (16), through titration with a Dornic solution (NaOH N/9) and expressed in °Dornic, where 0.1 mL of the NaOH N/9 represents 1 °D.

Determination of apparent viscosity of the yogurts

Apparent viscosity was determined with a Searle type pipe rheometer from Brookfield, model R/S plus SST 2000, equipped with the Rheo 2000 software, produced by Brookfield Engineering Laboratories, Inc., USA. Measurements were made at 10 °C and 25 °C. These are temperatures of typical yogurt consumption and the general oral temperature (17). The measuring system adopted utilized the DG DIN sensor, with deforming rate of 10 s⁻¹. This experiment lasted for 2 minutes and generated a total of 30 points. Results were expressed in mPa.s.

Statistical analysis

Results of physicochemical determinations were analyzed in a completely randomized design (CRD) (18) model, with 5 yogurt formulations and 2 repetitions. The effect of yacon flour supplementation was evaluated via regression analysis, in which linear and quadratic effects were tested according to changes in the concentration of yacon flour in the yogurt.

The SAS (Statistical Analysis System – SAS Institute Inc., North Carolina, USA, (19), licenced to the Universidade Federal de Viçosa – UFV (Federal University of Viçosa) was used.

RESULTS AND DISCUSSION

Centesimal composition of the yogurt

Results of the centesimal composition of the yogurts are given in table 1.

Protein and lipid contents presented no significant variation ($p>0.01$) among the yogurts supplemented with yacon flour. This was expected since the yacon root has low concentrations of these compounds (4). This indicates the little influence that yacon may have on yogurt composition when

used as an ingredient.

Protein content of the yogurts was between 3 and 4 %. This is in agreement with Brazilian regulations that demand a minimum of 2.9 % (20). Lipid content was lower than 0.5 % so that the yogurt in the present study could be classified as a low fat product according to the 29th ordinance (21), and in conformance with GMC 47/97, it was classified as a skimmed yogurt (20).

With regards to water, ash, IDF, SDF, FOS, inulin and carbohydrate contents, the addition of different levels of yacon flour resulted in significant changes ($p<0.01$). Regression models were adjusted to evaluate variation of these components due to yacon flour supplementation to the yogurt (table 2).

Greater concentrations of solids (ash, total dietary fiber and carbohydrates) for the same amount of product results in a linear reduction of water observed as yacon flour concentration increased. Therefore, a smaller concentration of solids and greater concentration of water was observed in the control yogurt when compared to yogurts with yacon flour.

A proportional growth in ash content was observed as the level of yacon flour added to the yogurt formulations increased in comparison to the control yogurt. This growth may be caused by the higher levels of phosphorus and potassium in the flour, since yacon has significant concentrations of such minerals, 23.4 mg/100 g of phosphorus and 170.7 mg/100 g of potassium (10).

Increase in the addition of yacon flour promoted a slight increase in the amount of IDF, SDF, FOS and inulin in the yogurts.

According to Brazilian regulations, functional foods are those which present at least 1.5 g of dietary fiber, FOS or inulin in liquid food per ready to eat portion (21). Considering a 200 mL yogurt portion, none of the yogurts in this study reached the necessary amount of total dietary fiber, FOS and/or inulin required. However, the yogurts containing more than 2.56 % of yacon flour presented a total dietary fiber content ranging from 2.06 to 2.76 % per portion (table 1), meeting the recommended levels. Therefore, the yogurts containing

TABLE 1

Mean values and standard deviation for centesimal composition and caloric value of the yogurts added of yacon flour.

Components (%)	Control yogurt	Yogurt with 1.58 % YF*	Yogurt with 2.56 % YF*	Yogurt with 3.00 % YF*	Yogurt with 3.86 % YF*
Water	91.11 ± 0.71	90.55 ± 0.61	89.73 ± 0.50	89.43 ± 0.82	87.62 ± 0.95
Proteins	3.72 ± 0.15	3.92 ± 0.39	3.65 ± 0.11	3.46 ± 0.09	3.94 ± 0.16
Lipids	0.02 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	0.01 ± 0.01
Ashes	0.70 ± 0.11	0.85 ± 0.01	0.87 ± 0.01	0.81 ± 0.02	0.91 ± 0.01
TDF**	0	0.70	1.03	1.11	1.38
IDF	0	0.25	0.41	0.48	0.61
SDF	0	0.04	0.06	0.07	0.09
FOS	0	0.14	0.17	0.17	0.20
Inulin	0	0.27	0.39	0.39	0.48
Carbohydrates	4.45	3.97	4.71	5.16	6.14
Caloric value***	32.9	31.7	33.5	34.8	40.4

* Yacon Flour.

** Total dietary fiber obtained through adding the insoluble dietary fiber (IDF), the soluble dietary fiber (SDF), FOS and inulin.

*** Caloric value (kcal/100 g) calculated based on the results of protein, lipids and carbohydrates.

The standard deviation was obtained based on 2 repetitions for each yogurt sample.

more than 2.56 % of yacon flour may be considered sources of total dietary fiber claimed to be functional.

Values of total dietary fiber, FOS and inulin in the yogurts (determined through the enzymatic-gravimetric and HPLC methods) were lower than expected. This may be due to the enzymatic degradation of FOS and inulin into sucrose, fructose and glucose which occurs during storage of yacon flour (21), since the yacon used in the production of the yogurt was stored in refrigerators (at 10 °C) for seven months.

It is also noticeable that the amount of carbohydrates in the yogurt tends to decrease when yacon flour is added, presenting minimum levels when the yogurt contains 1.1 % yacon flour. The yogurts with less addition of yacon flour presented a slight reduction in water content and an increase in total dietary fiber compared to the control yogurt. This fact is rather justifiable because, the same quantity of yogurt presents a reduction in the level of carbohydrates, something that asks for the definition of a quadratic effect to account for such behavior. Bearing this in mind, it is justified that the same quantity of yogurt presents a reduced level of carbohydrates, something that requires the definition of a quadratic effect to account for such behavior (table 2). Since the difference in water content between the yogurts with more than 1.1 % yacon flour and the control yogurt is high, a growing level of carbohydrates can be observed following the increase of yacon

flour concentration.

The caloric value ranged from 31.7 to 40.4 kcal/100 g of yogurt. This is lower than value defined by the Brazilian Table of Food Composition (TACO, 23), in which skim yogurt provides 41 kcal/100 g of the product. The caloric value in this study was calculated based on protein, lipid and carbohydrate contents. Protein and lipid content did not present significant variations ($p>0.01$) among the studied yogurts. The increase in caloric value may be due to the change in carbohydrate content in the yacon flour. Results suggest that the addition of yacon flour to yogurt has little effect on the caloric value. Moreover, the product has increased level of dietary fiber which may cause a slower absorption of carbohydrates in the intestinal tract.

Results of yogurt physicochemical analysis

Results observed for the yogurt L^* , a^* and b^* color space coordinates, pH values, total soluble solids (TSS) and acidity are shown in table 3.

Analysis of variance showed that yogurts differed significantly ($p<0.01$) in L^* , a^* and b^* color values, TSS and acidity. The pH did not change significantly ($p>0.01$) as the amount of yacon flour added to the yogurt increased. Average pH values for all five yogurts was 4.49 with mean values ranging from 4.28 to 4.69 (table 3). This is in agreement with Brazilian regulations which suggest a pH value of 4.5 for fermented milk

TABLE 2

Regression equations for the variation of the water content, ash, IDF, SDF, FOS and inulin due to yacon flour addition (X) and their respective coefficient of determination (R^2) and probability value for the regression model F.

Component	Linear regression models	R^2	Prob > F
Water	$0.91 - 0.01X$	0.84	< 0.0001
Ashes	$0.73 + 0.05X$	0.77	0.0404
IDF	$0.1591X$	0.99	< 0.0001
SDF	$0.02X$	0.99	< 0.0001
FOS	$0.02 + 0.05X$	0.91	< 0.0001
Inulin	$0.03 + 0.12X$	0.96	< 0.0001
Carbohydrates	$4.41 - 0.64X + 0.29X^2$	0.99	< 0.0001

X = % of Yacon flour

TABLE 3

Mean values and standard deviation of the L^* , a^* and b^* coordinates, pH, total soluble solids and acidity of the yogurts added of yacon flour.

Parameters	Control yogurt	Yogurt with 1.58 % YF*	Yogurt with 2.56 % YF*	Yogurt with 3.00 % YF*	Yogurt with 3.86 % YF*
Color L^*	76.03 ± 1.68	74.97 ± 0.21	72.73 ± 0.29	71.93 ± 0.21	67.77 ± 1.69
a^*	1.3 ± 0.17	1.87 ± 0.15	2.23 ± 0.11	2.37 ± 0.21	1.83 ± 0.15
b^*	14.37 ± 0.11	17.57 ± 0.21	18.43 ± 0.30	18.23 ± 0.21	17.2 ± 0.17
pH	4.28 ± 0.03	4.28 ± 0.08	4.69 ± 0.35	4.54 ± 0.01	4.68 ± 0.01
TSS**	7.33 ± 0.30	8.57 ± 0.30	9.67 ± 0.06	9.73 ± 0.29	11.8 ± 0.00
Acidity	86 ± 0.49	97 ± 0.14	95 ± 0.28	77 ± 0.14	76 ± 0.00

* Yacon flour; ** Total soluble solids

The average and the standard deviation were obtained based on the results of 2 repetitions of each yogurt sample.

products, including yogurt. Yogurts with pH values lower may be rejected by consumers and would favor coagulation due to reduction of proteins and lead to whey separation. Values of pH higher than 4.6 may also result in whey separation since the gel is not formed (24).

Regression equations were adjusted ($p < 0.01$) for LAB color coordinates and for TSS and acidity values, table 4.

A regression analysis showed a linear effect of yacón flour supplementation on L^* values. The quadratic model fitted best for a^* and b^* values. Reduction of L^* values with increase in the amount of yacón flour indicated darkening of the yogurts. This may result from coloring of flour, which happens due to enzymatic browning reactions by the presence of phenolic compounds (4), and non-enzymatic browning during yogurt processing. However, all yogurts may be considered light-colored, since on a scale ranging from 0 to 100, they presented values over 50 ($L^* > 50$) (25).

The a^* and b^* values were in the red and yellow regions, respectively, since readings were on the positive side of the scale, with higher intensity for yogurts with 2.5 and 2.6 % of yacón flour. This indicates that the combination of the positive a^* and b^* chromes results in a brown color. Total soluble solids (TSS) contents increased linearly with addition of yacón flour to the yogurt. This may be linked to the higher level of fructans (FOS and inulin) in the yogurts with higher concentrations of yacón flour.

A quadratic model was chosen to explain acidity variation with yacón flour supplemented yogurt. It is observed that yogurts containing 1.4% yacón flour presented acidity levels (table 4). This accounts for the growing reduction of the acidity with increase in yacón flour concentration; and may also be related to the increased amount of TSS (table 3), since there is a strong inverse relation between TSS and acidity (26).

Results of apparent viscosity measurement of the yogurts

Yogurts with yacón presented a shear-thinning fluid behavior, i.e., their apparent viscosity decreased as the shear rate increased. This reduced gumminess during intake (27).

The control yogurt presented a higher apparent viscosity than the yogurt with 1.58 % yacón flour, both at 10 °C and 25 °C, as can be seen in figure 1.

The apparent viscosity of yogurts evaluated at 25 °C was lower than that at 10 °C. This behavior is quite common in food fluids (28) since increase in temperature promotes a decrease in viscosity. This occurs because the movement of suspended

particles increases (29).

These apparent viscosity variations due to the addition of yacón flour were significant ($p < 0.01$) for the yogurts at both temperatures, 10 °C and 25 °C, making it possible to adjust models to predict this behavior, as can be seen in Table 5.

As expected, when taking into account the lower apparent viscosity of yogurt with 1.58 % yacón flour when compared to control, variation of apparent viscosity at both temperatures generated quadratic equations, with a high coefficient of determination ($R^2 > 90$ %).

FOS and inulin are soluble dietary fibers capable of interacting with the aqueous portion of the yogurt. They are highly hygroscopic substances which act as food stabilizers because of their capability to form a more cohesive mesh, similar to gel (30), thus changing system viscosity. Despite this, these products are not able to form a gel after heating and cooling processes at some concentrations (31). Therefore, it is suggested that the FOS and inulin content in yogurts with 1.1 % and 0.85 % yacón flour may have been insufficient to form gel and increase product viscosity at temperatures of 10 °C and 25 °C.

Additionally, yogurt carbohydrate levels also have an influence on product apparent viscosity, and carbohydrate content also presented a quadratic effect due to yacón flour concentration, corroborating the quadratic regression model adjusted for apparent viscosity.

CONCLUSION

Addition of yacón flour to yogurt leads to products with low fat and low caloric values. Yogurts supplemented with 2.56 % to 3.86 % yacón flour may be considered prebiotics. They were capable of providing dietary fiber concentrations higher than the minimum recommended by Brazilian regulations.

It was not possible, however, to obtain yogurts considered source of FOS and inulin as expected. Further studies are needed in order to optimize the use of even greater yacón concentrations in food products given the notable benefits it can bring to consumers.

RESUMEN

La harina de yacón se ha utilizado en muchos productos alimenticios, debido a su alto contenido de fructooligosacáridos y inulina, compuestos que tienen propiedades promotoras de la salud. En este estudio, la harina de yacón fue utilizada como ingrediente en yogur "light" en las siguientes concentraciones: 1,58, 2,56, 3,00 y 3,86%. Se determinaron la composición centesimal, pH, sólidos solubles, acidez y la viscosidad

TABLE 4

Regression equations for the variation of the L^* , a^* e b^* color space coordinates, total soluble solids and acidity according to the concentration of the yacón flour (X) and their respective coefficient of determination (R^2) and probability value for the regression model F.

Parameters	Linear regression models	R ²	Prob > F
Color	L^*	$77.09 - 2.00X$	0.78
	a^*	$1.25 + 0.74X - 0.14X^2$	0.77
	b^*	$14.33 + 3.11X - 0.61X^2$	0.98
TSS**	$7.05 + 1.07X$	0.91	< 0.0001
Acidity	$87.30 + 10.77X - 3.75X^2$	0.70	0.0015

** Total soluble solids.

del yogur suplementado con yacón se determinaron. Los resultados fueron evaluados mediante un análisis de varianza y de regresión. La composición centesimal de los yogures permite que los clasifiquen como alimentos bajos en grasa, con bajo contenido de carbohidratos y que contenga fibra dietética, particularmente aquellos suplementados con más de 2,56% de harina de yacón, que puede considerarse como fuente de fibra y, en consecuencia, prebióticos. El análisis físico-químico reveló cambios significativos ($p < 0,05$) en el análisis de color, sólidos solubles, viscosidad y acidez a temperaturas de 10 y 25 °C con la harina de yacón en aumento.

Palabras clave: fructooligosacáridos, inulina, prebióticos, yogur, yacón.

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FIGURE 1

Variation of the apparent viscosity of the yogurts containing 0%, 1.58 %, 2.56 %, 3.00 % and 3.86 % of yacón flour at the temperatures of 10 °C and 25 °C.

TABLE 5

Regression equations for variation of viscosity of yogurts with yacón flour at 10 and 25 °C due to concentration of yacón flour (X) with their respective coefficients of determination (R^2) and probability of F value for the regression model.

Temperature	Linear regression model	R ²	Prob > F
10 °C	495.85 – 199.26X + 90.78X ²	0.94	0.0020
25 °C	305.49 – 97.13X + 57.08X ²	0.99	< 0.0001

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