Article

Red spider in jackfruit: bioecology and biological efficacy of acaricides

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Abstract

Jackfruit (*Artocarpus heterophyllus*) has become an important fruit and represents a production option for tropical areas of Mexico. However, due to its recent introduction, information on its associated pests and diseases and management recommendations is still limited. In 2017, deformation of the leaves, discoloration of the beam and the presence of spider webs on the underside caused by an unknown mite were observed. The objective of this research was to identify the associated mite, determine its population distribution and fluctuation and evaluate the biological efficacy of acaricides. The study was conducted during 2018-2019 in Nayarit, Mexico. The identified mite is *Tetranychus pacificus* known as the red spider. It is distributed in all producing areas of jackfruit in Nayarit. It was mainly detected from November to June with greater infestation in the Tecuitata producing area (0.86 mites' leaf^{-1}) and Jalcocotan (0.57 mites' leaf^{-1}) of the municipality of San Blas. On average in September and October its presence is imperceptible; however, in El Capomo only in July was detected which probably indicates an initial stage of dispersal of the mite. Significant correlation was observed (β= 0.0489, r= -0.73, F= 0.0345, α= 0.05) of the population with the temperature, with a decrease in the population at a higher temperature and accentuated from 26 ° C. No correlation was observed with relative humidity. The highest temperature (27.9 °C) and relative humidity (88.2%) occurred in the month of July and September, respectively, months in which the lowest mite population was observed. The acaricides evaluated exercised significant control. At 21 days after application, differences occurred between treatments and the absolute control (Pr>F= 0.0245). With the application of azadirachtin (1.9 g of ia L^{-1} of water) and mineral oil (16.9 g of ia L^{-1} of water) a control of 75.9% and 72.5%, respectively, was obtained.

Keywords: *Tetranychus pacificus* Lam. (Moraceae), mites, control, jackfruit.

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Introduction

Jackfruit, *Artocarpus heterophyllus* Lam. (Moraceae), is native to southwestern India, currently grown in countries in Asia, Africa, America and the Caribbean (Muniappan *et al*., 2012). In Mexico, its cultivation is recent, with about 30 years of being introduced to Mexico it has had an important growth as an export product (Ulloa *et al*., 2007; Luna *et al*., 2013). With an area of 1 509 ha, an annual production of 22 192 t whose value amounts to just over 143.9 million pesos (SIAP, 2017), the jackfruit has become an important fruit and a production option in tropical areas of Nayarit and Jalisco, Mexico.

Due to its recent introduction and cultivation in Mexico, information about its pests and associated diseases and management recommendations is still limited. Among the few studies on pests is published by Rodríguez *et al*. (2017) who report some species of bedbugs and mealybugs associated with jackfruit. On the other hand, Hernández *et al*. (2018), report for the first time in Nayarit to *Piezogaster odiosus* (Stal.) and *Leptopharsa* sp., as phytophagous insects of this crop. Similarly, the pink hibiscus cochineal (*Maconellicoccus hirsutus* Green) is considered an important pest of the jackfruit in Mexico (SENASICA, 2016). Lacking more phytosanitary information, technicians and producers make recommendations and applications of broad spectrum pesticides when observing damage to the crop.

In most cases, the identity, biology, habits, distribution, seasonal fluctuation and damage associated with these pests are unknown. In this sense, in 2017, in Nayarit, damage to the foliage, deformation, discoloration of the beam, and the presence of cobwebs in the underside were observed, possibly caused by the mite known as the red spider according to reports from the producers themselves. Therefore, the objectives of the present investigation were to confirm the presence of red spider and its identification, determine its distribution and population fluctuation or its relationship with temperature and relative humidity in Nayarit.

In addition, in order to provide a tool for producers to control this new pest in jackfruit, biological efficacy tests of several acaricides were carried out, most of them recommended and currently applied by technicians and producers, but without a technical support, mainly in the use of the dose and type of product used.

Materials and methods

Identification of the species of red spider observed

The samples collected from red spider were sent to the National Phytosanitary Reference Center of the National Service of Health, Safety and Agrifood Quality for identification. The description of Lee *et al*. (1985); Seeman and Beard (2011).

Distribution, population fluctuation and its relationship with environmental factors

Sampling was done at four sites located in the main producing areas of jackfruit in Nayarit. The predominant climate in the study area according to García (2004) is warm subhumid with rains in summer ($AW_1(x^1)$. With predominant vegetation of dry evergreen forest and subdeciduous (INEGI, 2018). Municipality of San Blas. Site 1 Jalcocotan, coordinates: 21.2938 north latitude, -105.0457 west longitude at 576 meters above sea level (masl) Site 2. Tecuitata, coordinates: 21.2626 north latitude, -105.0857 west longitude at 252 masl. Site 3.

El llano, coordinates: 21.2730 north latitude, -105.1112 west longitude at 18 meters above sea level. Municipality of Compostela. Site 4. El Capomo, coordinates: 21.0613 north latitude, -105.1035 west longitude at 103 meters above sea level. At each sampling site, a WatchDog (Spectrum Technologies, Inc. Aurora, Illinois, USA) micro station was placed to record relative humidity and temperature. Sampling was done based on what was suggested by Southwood (1978) and Pedigo and Rice (2009) for estimates of population density per unit of habitat.

In each site, an orchard between eight and ten years of age was chosen with the greatest possible homogeneity in terms of cultivated phenotypes since there are several materials or selections considered as varieties (Luna *et al*., 2013) and although these are not characterized or registered in a catalog, the phenotypic differences are notable. Sampling was done with a periodicity of two to three weeks. Through previous sampling the damage of the red spider on the underside and foliage beam was observed, no damage to flower or fruit was observed. At each site they were randomly selected 30 leaves five to ten trees crossing the garden in a random direction.

The sample size was estimated as suggested by Karandinos (1976): $n= (s/Em)^2$, where n= sample size; *s*= standard deviation; *E*= default standard error (coefficient of variability of the mean= 0.2) and *m*= mean. The count was direct in the field with the help of a 30x magnifying glass, the number of mites per leaf on both sides of it was counted. A comparison of the monthly population average between the sampled sites and their relationship with temperature and humidity was made. Prior to its statistical analysis, the data from each sampling were transformed using the formula $x= \sqrt{(y+0.8)}$, where y= average value observed; the foregoing, in order to observe greater normality of the data and at the same time make the variance of the mean independent.

A comparison of means between sampling sites (LSD, $\alpha= 0.1$) was performed. The regression coefficient (β) and Pearson's correlation index (r) were calculated under the assumptions underlying the linear regression, to determine the ratio of the average population fluctuation of the sampling sites (dependent variable) between the average temperature (*tm*) and average environmental humidity (*PAH*) (independent variables) and with the interaction of these (*tm***PAH*), the least squares method was used (Daniel, 2011).

Also, to determine the statistical significance of the linearity (r) between the observed variable, the Fisher statistical test (F) was performed to check H_0: $\beta= 0$, H_A: $\beta\neq 0$ with $\alpha= 0$. The program of SAS® statistical analysis version 9.3 (2010).

Evaluation of biological efficacy of acaricides

Acaricidal products available in the local market in the jackfruit producing area were used. The study was conducted within the garden at Site 2, Tecuitata, coordinates: 21.2626 north latitude, -105.0857 west longitude at 252 meters above sea level. The evaluations were made from March to April, the following products and their doses were evaluated: 1) sulfur (Intersul 725 ™, Internacional Química de Cobre, SA de C. V.) 2.5 mL L^{-1} of water; 2) abamectin (Hortimec 1.8 ™, Agroquimica Tridente, SA de CV) 1 mL L^{-1} of water; 3) potassium salts of fatty acids (Des-X

™, Summit Agro de México, SA de CV) 18 mL L^{-1} of water; 4) neem extract (Trilogy ™, Summit Agro de México, SA de CV) (3 mL L^{-1} of water; 5) mineral oil (Akaroil ™, Altiara) (20.0 mL L^{-1} of water); and 6) control only with water application.

An application was carried out with Stihl® Mod. SR420 motorized pump, a water consumption of 1.2 L tree. The treatments were distributed in complete randomized blocks with five repetitions per treatment. Each repetition consisted of two trees leaving a row without applying between repetitions. To count the population of red spider, ten leaves were sampled by repetition chosen at random from the middle part of the tree canopy. The counting was done in the field with the help of a 30x magnifying glass observing on both sides of the leaves. A previous sampling and four samples after the application of treatments were made.

Analysis of variance and comparison of means of treatments with Duncan (α= 0.05) was performed on each sampling date after application. In addition to the above, the biological efficacy of each treatment was compared with respect to the absolute control at each sampling date, the Henderson and Tilton formula (1955) was used for this.

Results and discussion

Species identification

The red spider identified is *Tetranychus pacificus*. The description according to Lee *et al*. (1986); Seeman and Beard (2011) is the following: male, dorsal stretch marks without lobes. Empodio I uncinado, provided with a strong spur, empodio II with smaller spur and empowers II-IV with tiny dorsal spurs. Empodia II-IV have long proximal and free hairs. Edeago without protuberance, sigmoid and presents a small projection on the anterior margin. The color of both sexes depends on the host and the time of the year, and can be deep red, even dark brown.

In the case of what was found in jackfruit, only red mites with different shades have been observed. To our knowledge, this is the first report of *T. pacificus* associated with *A. heterophyllus*. Other phytophagous mites have been recorded in other species of the *Artocarpus* genus; in this regard, Flechtmann *et al*. (1999) mention *Paratetranychus biharensis* Hirst associated with *Artocarpus altilis* in France, while Yusof and Zhang (2003) observed this same species in *Artocarpus comminis* in Malaysia as well as *Tetranychus malaysiensis* Ehara causing damage in *Artocarpus champeden*. On the other hand, Gutierrez and Schicha (1983) report *Tetranychus ludeni* Zacher as an incipient *Artocarpus incisa* phytophagus in Sydney, Australia. Lee (1986) reports to *Eutetranychus banksi* McGregor of *A. altilis* in Maui, Oahu.

In India, Gupta and Gupta (1994) mention *Panonychus citri* McGregor, *Panonychus ulmi* Koch and *Oligonychus mangiferus* Rahman and Sapra associated with *Artocarpus integrifolia*. All Tetranychidae members are phytophagous and constitute a very important group of plague mites in agriculture, most of the damage is in the foliage and in heavy infestations in fruits and stems (NAPPO, 2014). *T. pacificus* begins its damage with chlorotic points in the beam, until it reaches total tanning (Badii *et al*., 2010; Vacante, 2016). *T. pacificus* additionally in the jackfruit can cause deformation of the leaves by damaging them in early stages of their development.

In this regard, Vacante (2016) mentions severe damage caused by low populations of *T. pacificus* in pear, citrus and other crops, suggesting that the injection of toxins into plant tissue might be involved. It is a serious plague because of its wide distribution, from warm subtropical zones such as Mexico to temperate zones such as Canada (Seeman and Beard, 2011). The threshold of action for *T. pacificus* is variable and depends on the susceptibility of the host, in vines for example 1 200 mites leaf^{-1} 4 weeks^{-1} do not cause damage in production, while in almond high populations reduce 13-19% young tree yield in the next year of production (Badii *et al*., 2010).

As it is a recent crop and barely detected as a *T. pacificus* pest in jackfruit, it would be necessary to determine the threshold of action, direct and indirect damages and quantify the damages in production. In grapes, damage by *T. pacificus* induces a reduction in sugars and yield losses (Vacante (2016). In corn they cause premature drying of the foliage which is associated with a reduction in yield (Jeppson *et al*., 1975). Sites like Tecuitata have come to observe trees with symptoms of tanning and with 100% of the damaged foliage.

Distribution, population fluctuation and its relationship with environmental factors

In the four sampled sites, *T. pacificus* was found in the cultivation of jackfruit in Nayarit (Table 1). However, the largest population is located in the area of Tecuitata and Jalcocotan in the municipality of San Blas. The differences between sites are significant (Table 1), the highest annual average occurred in Tecuitata with 0.86 mites' leaf^{-1}, followed by Jalcocotan 0.57 mites leaf^{-1}. In both sites the largest population was observed in January with 4.51 and 5.23 mites leaf^{-1}, respectively.

Table 1. Population distribution and fluctuation of *T. pacificus* in Jackfruit. Nayarit, Mexico 2018-2019.

	Mites leaf^{-1}				
Month	El Capomo	El Llano	Tecuitata	Jalcocotan	Average
February	0	0.03	0.66	0.2	0.22
March	0	0.06	0	0	0.02
April	0	0.1	0.96	0.46	0.38
May	0	0	0.26	0.33	0.15
June	0	0.66	0	0	0.17
July	0.16	0	0	0.03	0.05
August	0	0	0	0.53	0.13
September	0	0	0	0	0
October	0	0	0	0	0
November	0	1.7	0	0	0.43
December	0	0.16	3.96	0	1.03
January	0	0	4.51	5.23	2.44
Average*	0.01b	0.23a	0.86ab	0.57ab	0.34

*= means with different letters are statistically different (LSD, α= 0.1).

The lowest annual average was found in El Capomo with 0.01 mites leaf^{-1}, it was only detected in the month of July and El llano with 0.23 mites leaf^{-1}. In this region, the cultivation of the jackfruit began just over 20 years ago (Luna *et al*., 2013) and it is also where the largest area is presented (SIAP, 2017). The average annual temperature at the four sampling sites was statistically the same in El Capomo (25.4 °C), El Llano (25.5 °C) and Tecuitata (25.1 °C) (Pr> F= 0.0231) and different in Jalcocotan (22.7 °C), with a minimum and maximum temperature of 21.5 °C, 22.2 °C, 21.8 °C, 19.3 °C and 29.4 °C, 29.1 °C, 28.3 °C, 24.9 °C, respectively. However, the average annual temperature of the four sites is in the optimal range for the development of *T. pacificus* as indicated by Badii *et al*. (2010).

Regarding the annual environmental humidity, no significant differences were observed between the sampled sites. This ranged an average of 76.9% in Jalcocotan to 79.8% in El Capomo. With a maximum of 90.2% and a minimum of 46.2%, both occurred at the Jalcocotan site, in the municipality of San Blas. The largest population of mites occurred in the months of January to April, with a maximum overall average in January of 2.44 mites' leaf^{-1} (4.51 and 5.23 mites leaf^{-1} at the sites of Tecuitata and Jalcocotan, sites closest to each other). As of July, the population decreases until it is imperceptible in the months of September and October, a period of rainfall and more humidity in the sampling sites.

The life cycle of *T. pacificus* and due to its direct relationship with the population increase or decrease depends on the host, temperature and humidity; at a temperature of 30-35 °C, the time of egg-to-adult development of *T. pacificus* is six days, while at 25 °C it is 10-14 days (Badii *et al*., 2010). In general, high temperatures and low ambient humidity favor the development of *T. pacificus* and its associated damages (Vacante, 2016). In other species such as *Olygonichus mangiferus* the optimum temperature and relative humidity are 15-31 °C and 65-75%, respectively, conditions outside these ranges significantly affect their development, inhibiting their growth or causing their death (Badawi *et al*., 2011).

Although the annual population average of *T. pacificus* in the sampled sites is statistically different, it is probable that these differences are due, among other causes, to the short time that jackfruit has been cultivated in Nayarit, rather than to environmental factors since they do not exist large differences in temperature and humidity, the cultivation of jackfruit began in the San Blas region (Jalcocotan, Tecuitata and El Llano sites) and has been expanding to other areas of the state (El Capomo site) in the last ten years. With the increase in the area and distribution of jackfruit, the distribution and abundance of pests would increase.

Correlation with temperature and humidity

In the case of the population density-environmental humidity ratio, a significant correlation was not observed (β= 0.64, r= -0.1467, F= 0.5572, α= 0.05) (Figure 1), on the contrary, with the temperature it is observed a significant correlation (β= 0.0489, r= -0.736, F= 0.0345, α= 0.05) (Figure 2) with a decrease in the population at a higher temperature, accentuating from 26 °C to 27.9 °C and not significant with the interaction ($tm*PAH$) (F= 0.1426, α= 0.05). The highest temperature (27.9 °C) and relative humidity (88.2%) occurred in the month of July and September, respectively, months in which the lowest mite population was observed.

On the contrary, the lowest temperature (21.2 °C) and relative humidity (62%) were recorded in December and April, respectively, months with a greater population of mites. However, as mentioned above, it is likely that the distribution of red spider in jackfruit in Nayarit is in an initial stage of dispersal due to the increase in surface area and greater distribution of the crop.

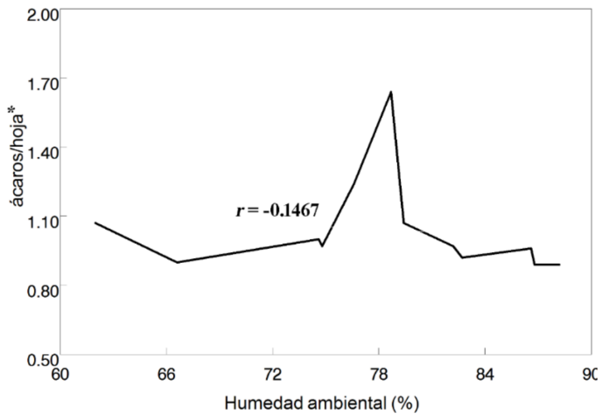

Figure 1. Population fluctuation of *T. pacificus* and its relationship with relative humidity in the jackfruit crop *A. heterophyllus*. *= transformed data, 2018-2019, Nayarit, Mexico

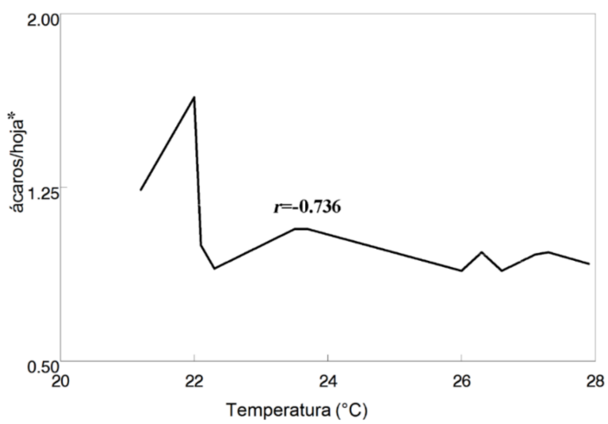

Figure 2. Population fluctuation of *T. pacificus* and its relationship with temperature in the jackfruit crop *A. heterophyllus*. *= transformed data. 2018-2019. Nayarit, Mexico

Evaluation of biological efficacy of acaricides

The control of *T. pacificus* in the cultivation of jackfruit had different statistical effects with the treatments evaluated (Tables 2 and 3). In the first sampling five days after application, a significant reduction of the population was observed and statistical differences (Pr>F= 0.0056) occurred with respect to the absolute control. There were no significant differences between acaricide treatments; however, the treatment with potassium salts of fatty acids exerted the greatest control with 95.4% efficacy, followed by abamectin with 76.9% and sulfur with 76.2% efficacy (Table 2).

Table 2. Average number of *T. pacificus* mites in jackfruit after the application of treatments.

Treatment	[1]g of ia L^{-1}	[2]Dose (mL L^{-1} of water)	[3]Treatment means					
			Previous	5 dda	8 dda	14 dda	21 dda	28 dda
1) Sulfur	725	2.5	3.6±1	0.7b±0.3	0.1c±0.1	1.6bc±0.4	0.2b±0.1	0.7±0.2
2) Abamectin	18	1	3.2±0.7	0.6b±0.3	0.8bc±0.2	1.6bc±0.4	0.4b±0.2	1.2±0.3
3) Potassium salts of fatty acids	582.8	18	4±0.2	0.1b±0.04	0.2c±0.1	0.3c±0.1	0.1b±0.06	0.3±0.1
4) Nim Extract	639.9	3	4.1±0.9	1.5b±0.5	1.8b±0.6	1.4bc±0.5	0.6b±0.4	1.6±0.6
5) Mineral oil	847	20	3.3±0.7	2.7b±1.2	3.4a±0.6	4a±0.7	0.1b±0.06	0.5±0.2
6) Absolute control	-	Only water	2.2±0.8	6.5a±2.1	3.3a±0.3	3.3a±0.8	1.5a±0.5	1.4±0.6

[1]= grams of active ingredient in commercial product; [2]= dosis of formulated product; [3]Mites per leaf in days after application (±standard error).

In this regard, Stavrinides and Mills (2009) evaluated the efficacy of sulfur (11.5 g of ia L^{-1} of water) against *T. pacificus* in the vine cultivation and observed a significant reduction in their population, also mentioning that sulfur had no effect about its predator *Galendromus occidentalis* Nesbitt. In the second evaluation, eight days after application, significant differences (Pr> F= 0.0001) were observed between the treatments and the absolute control. The most effective treatments in the control were sulfur and potassium salts of fatty acids with 100% and 82.3%, respectively. In the treatment with mineral oil no significant effect was observed with respect to the absolute control (Table 2).

At 14 days after application the population of *T. pacificus* in the treatments was statistically different (Pr> F= 0.0035). The treatment with greater control was the potassium salts of fatty acids with 92.4% efficiency. The mineral oil treatment was statistically equal to the absolute control. At 21 days after application, significant differences occurred between treatments and the absolute control (Pr> F= 0.0245). Although the differences between the treatments were not significant, the treatments with greater control were those of azadirachtin and mineral oil with 75.9% and 72.5% efficacy, respectively (Table 3).

Table 3. Percentage of control efficacy of *T. pacificus* in jackfruit after the application of treatments.

Treatment	[1]g of ia L^{-1}	[2]Dose (mL L^{-1} of water)	Treatment effectiveness percentage				
			5 dda	8 dda	14 dda	21 dda	28 dda
1) Sulfur	725	2.5	76.2±19.1	100a±0	49ab±17.3	65.9±19.3	34.8±16.3
2) Abamectin	18	1	76.9±19.3	60.2ab±17.8	60.4a±15.7	42±21.2	18.1±18.1
3) Potassium salts of fatty acids	582.8	18	95.4±4.3	82.3a±17.7	92.4a±4.7	40±24.4	19.2±19.1
4) Nim extract	639.9	3	74.2±18.9	69.5a±9.7	69.6a±18.3	75.9±19.2	33.8±21.2
5) Mineral oil	8470	20	64.6±19.7	27b±13.6	7.3b±7.2	72.5±18.6	43.6±18.1
6) Absolute control	-	Only water	-	-	-	-	-

[1]= grams of active ingredient in commercial product; [2]= dose of formulated product; Control efficiency (±standard error); dda= days after application.

In the last evaluation at 28 days after application, the population of *T. pacificus* was not statistically different between the treatments and the absolute control. The highest control efficacy observed in this evaluation was in the treatment with mineral oil with 43.6% (Table 3). The above indicates a period of effectiveness with significant differences in the treatments evaluated, with the exception of mineral oil, which exercised an irregular control on the different sampling dates, 21 days after the application with an efficiency of 40 to 75.9%.

Conclusions

The species of red spider associated with the jackfruit in Nayarit is *Tetranychus pacificus*, a new report in this crop. Causes damage to the foliage, starting with yellow spots on the beam, deformation of the beam and in high infestations causes a general discoloration turning yellow-tan and finally causing its fall. The severe damage caused by low populations in crops such as pear, corn, almond, grapevine and citrus make it an important pest for the jackfruit. Its dispersion in Nayarit could be in an initial stage, so it should be considered as a pest with potential to cause damage to the crop and be taken into account for its agronomic management.

Based on the observed population fluctuation is mainly related to temperature. Its presence is observed from November to August and is imperceptible in the months of September and October. The largest population of red spider was observed in the months of December and January.

The control of *T. pacificus* in the cultivation of jackfruit had different statistical effects with the treatments evaluated. Five days after the application, a significant reduction of the population was observed and statistical differences occurred with respect to the absolute control, the treatment with potassium salts of fatty acids (10.4 g of ia L^{-1} of water) exercised the greatest control with 95.4% effective, followed by abamectin (0.018 g of ia L^{-1} of water) with 76.9% efficiency.

At 21 days after application, the treatments with the highest control were azadirachtin (1.9 g of ia L^{-1} of water) and mineral oil (16.9 g of ia L^{-1} of water) with 75.9% and 72.5% efficacy, respectively.

With these results the objectives set are achieved; however, further studies are necessary for a better understanding of the relationship *T. pacificus* with *Artocarpus heterophyllus*. Biology studies, life cycles, associated natural enemies, phenotype tolerance and their effect on performance are required, in addition to acaricide evaluations with different mechanism of action and their impact on natural enemies. All of the above will allow the development of a better integrated management program for *T. pacificus* in the cultivation of jackfruit.

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