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# Evaluation of fungicides used in the management of black Sigatoka in banana cultivation

Evaluación de fungicidas utilizados en el manejo de Sigatoka negra en el cultivo de banano

Avaliação de fungicidas utilizados no manejo da Sigatoka negra na bananicultura

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## Abstract

The main phytosanitary problem of commercial bananas is black Sigatoka (BS; *Mycosphaerella fijiensis*), which causes damage to leaf area, loss of exportable quality, and low yields. The management of BS with mixtures of four systemic fungicides in different combinations in the border and central area of three banana plantations, and its effect on the severity of this disease were evaluated. The study was carried out in Ecuador, province of El Oro, Pasaje canton, at the ‘‘El Playón’’, ‘‘Mega Impulso’’ and ‘‘Lolita’’ farms; in an area of 5 hectares of the Williams cultivar with 10 years of production, 50 plants were selected in the vegetative phase in the borders and center of the plantation, four treatments were evaluated: T1 (Triazole+Amine), T2 (Pyrimethanil+Spiroxamine), T3 (Difenoconazole+Amine) and T4 (Amine+Pyrimethanil) and three replicates, with four applications every 14 days. Severity was assessed for 10 weeks using the Stover scale. The experimental design was a randomized block design and the data were analyzed by two-way ANOVA. The greatest fungicidal effect was achieved in ‘‘El Playón’’, the severity for leaf 4 in the border area was 37.5 % and 38 % in the center. On leaf 5, ‘‘El Playón’’ 55 %, ‘‘Mega Impulso’’ 60 %, and ‘‘Lolita’’ 72.5 % reached a severe value. The highest average number of functional leaves was obtained in ‘‘Mega Impulso’’ and the highest average number of old leaves free of streaks in ‘‘Lolita’’. The fungicides applied controlled BS, due to the low percentages of disease severity.

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## Resumen

El principal problema fitosanitario de los bananos comerciales es Sigatoka negra (SN; *Mycosphaerella fijiensis*), causa daño al área foliar, pérdida de calidad exportable y bajos rendimientos. Se evaluó el manejo de SN con mezclas de cuatro fungicidas sistémicos en diferentes combinaciones en la zona de linderos y centro de tres bananeras y su efecto sobre la severidad de esa enfermedad. Se realizó en Ecuador, provincia de El Oro, cantón Pasaje, en las haciendas "El Playón", "Mega Impulso" y "Lolita"; en una superficie de 5 hectáreas del cultivar Williams con 10 años de producción, se seleccionaron 50 plantas en la fase vegetativa en los linderos y centro de la plantación, se evaluaron cuatro tratamientos: T1 (Triazol+Amina), T2 (Piremetanil+Espiroxamina), T3 (Difeconazol+Amina) y T4 (Amina+Piremetanil) y tres repeticiones, con cuatro aplicaciones cada 14 días. La severidad se evaluó durante 10 semanas utilizando la escala de Stover. El diseño experimental fue de bloques al azar y los datos fueron analizados mediante ANOVA de dos vías. El mayor efecto de fungicidas se logró en "El Playón", la severidad para la hoja 4, en zona de linderos fue 37,5 % y el centro 38 %. En la hoja 5, "El Playón" 55 %, "Mega Impulso" 60 % y "Lolita" 72,5 % alcanzaron un valor severo. El mayor número promedio de hojas funcionales se obtuvo en "Mega Impulso" y el mayor promedio de hojas viejas libres de estría en "Lolita". Los fungicidas aplicados controlaron a SN, debido a los bajos porcentajes de severidad de la enfermedad.


**Palabras clave:** severidad, control químico, musáceas, estrías y manchas foliares.


## Resumo

O principal problema fitossanitário das bananas comerciais é a Sigatoka preta (SP; *Mycosphaerella fijiensis*), que causa danos na área foliar, perda de qualidade exportável e baixos rendimentos. A gestão do SP com misturas de quatro fungicidas sistémicos em diferentes combinações foi avaliada na zona fronteiriça e central de três plantações de banana e o seu efeito na gravidade desta doença. Foi realizada no Equador, província de El Oro, cantão de Pasaje, nas fazendas "El Playón", "Mega Impulso" e "Lolita"; numa área de 5 hectares da cultivar Williams com 10 anos de produção, foram seleccionadas 50 plantas na fase vegetativa nas fronteiras e no centro da plantação, foram avaliados quatro tratamentos: T1 (Triazol+Amina), T2 (Pireometanil+Espiroxamina), T3 (Difeconazol+Amina) e T4 (Amina+Pireometanil) e três réplicas, com quatro aplicações de 14 em 14 dias. A severidade foi avaliada durante 10 semanas utilizando a escala de Stover. O desenho experimental foi um desenho de bloco aleatório e os dados foram analisados por ANOVA bidireccional. O maior efeito fungicida foi alcançado em "El Playón", a severidade para a folha 4, na zona fronteiriça foi de 37,5 % e o centro de 38 %. Na folha 5, "El Playón" 55 %, "Mega Impulso" 60 % e "Lolita" 72,5 % atingiram um valor severo. O maior número médio de folhas funcionais foi obtido em "Mega Impulso" e o maior número médio de folhas velhas livres de estrias em "Lolita". Os fungicidas aplicados controlaram SP, devido às baixas percentagens de gravidade da doença.


**Palavras-chave:** severidade, controlo químico, musaceae, estrias e manchas de folhas.

## Introduction

Bananas are a crop of economic and food importance to the world. In Ecuador, in the commercial and social sphere, it represents 2 % of the gross domestic product (GDP). The banana industry generates approximately 1 million families and benefits 2.5 million people, representing 6 % of the country's total population (García *et al*., 2019).

According to Yánez *et al.* (2020), 60 % of the area planted with bananas in Ecuador corresponds to the Williams cultivar and describe it as a medium-sized plant (between 3.5 and 4.0 m), of high production and susceptible to Black Sigatoka (*Mycosphaerella fijiensis* Morelet).

Cedeño *et al*. (2017) reported that black Sigatoka is the most destructive disease in banana crops because the fungus destroys the leaf area due to the excretion of the phytotoxin "Juglone", which interrupts the transport of electrons in the membranes of chloroplasts, causing necrosis and death of leaf tissue in the plant.

To prevent black Sigatoka from causing the loss of leaves of banana plants, it is necessary to monitor weekly the phytosanitary status of the crop and the application of fungicides to obtain an acceptable commercial production; however, this raises costs and producers see their incomes affected (Ramírez *et al.*, 2014).

In Ecuador, the most commonly used systemic fungicides are: amines (fenpropimorph), triazoles (epoxiconazoles), strobilurins, anilinopyrimidines, carboxamides, and guanidines, and the application cycles depend on the degree of infection, the frequency is 7 to 14 days in the rainy season and 28 days in the dry season.

This chemical control of the disease increasingly requires the application of more fungicides in mixtures and at low frequencies due to the resistance that the fungus has developed, which increases production costs by more than 30 % (Sepúlveda, 2015). In this sense, Cervantes-Alava *et al*. (2020) and Sánchez *et al.* (2021) highlighted that applications should be made taking into consideration the rotation indicated by the FRAC (Fungicide Resistance Action Committee) for the different chemical groups.

Regarding the systemic mode of action of the fungicides applied, Pérez (2006) pointed out that it allows them to enter at the level of the waxy layers and the cuticle in the leaf, highlighting that the chemical groups presented different solubility values: spiroketalamines and pyrimethanil (2.8); epoxiconazole (3.4); tridemorph (4.2); difenoconazole (4.3) and fenpropimorph (4.7).

Likewise, Murillo (2015) pointed out that the absorption and translocation of systemic fungicides depend on their lipophilicity, a characteristic that allows penetration at the level of the waxy layers and the cuticle of the leaf, and solubility in water, factors that substantially affect their systemic action.

The aerial spraying reaches to fumigate the entire area planted with bananas and especially in the borders, an area that receives twice as many products; however, in general, at this site, there is always high infection all year round.

Therefore, the objective of the research was to evaluate the management of black Sigatoka through the application in mixture of four systemic fungicides in different combinations in the border and central areas of the banana plantations "El Playón", "Mega Impulso", and "Lolita" and its effect on the severity of this disease.

## Materials and methods

The study was conducted in the southern region of Ecuador, in the province of "El Oro" Pasaje canton in banana plantations "El Playón", "Mega Impulso" and "Lolita". The study area has a humid tropical climate, with an average temperature of 24 °C, annual rainfall of 550 mm, and relative humidity of 80 %, with clay loam soils (Yánez *et al*., 2020).

The banana plantations had been established for 10 years with the Williams cultivar and with a subfoliar irrigation system. For the collection of data in the field, from the zones (center and border) 50 plants of more than 3 meters in height were selected in the vegetative phase, distributed in an area of 5 hectares, in each of the farms. Two evaluation sites were considered, a first zone subjected to normal frequency cycles called "center" that received a chemical load of fungicides respecting the FRAC guidelines, and a second zone of "borders" that received a greater chemical load due to the drift of the adjacent applications.

Of the 50 plants selected, the variables severity, old leaf free of streaks (OLFS), and number of total leaves (TL) were evaluated in 10 plants, 7 days after the application of fungicide mixtures for 10 weeks.

For the quantification of the severity, 40 cm from the apex towards the center of leaves 3, 4, and 5 were cut using a billhook. The percentage of severity was evaluated according to the Stover scale modified by Gauhl, which measures physiological parameters visible in the young leaves of plants ready for flowering, in which the evolutionary stages of the fungus and levels of infection were determined according to the degrees established by Gauhl (Quevedo *et al*., 2018). The values for the variable OLFS were considered according to the last leaf with streaks whose percentages were less than 5 % in plants with the presence of inflorescences (newly emerged acorn), in both zones within the test area, and the TL was calculated by counting the first leaf from the top to the base of the plant.

The applications of the mixtures of the systemic fungicides evaluated were made by aerial spraying (table 1), the products were prepared in emulsion at a volume of 3 gallons of water and 2 gallons of oil (Banole®) per hectare, the dose of the fungicides was as indicated on the label by the manufacturer and the frequency of rotation was 14 calendar days.

Using the SPSS statistical program, the data obtained were subjected to two-way analysis of variance according to the randomized block design with three replications. The separation of means was carried out by Tukey's test.

## Results and discussion

### Severity of Black Sigatoka

In the estimation of the effect of the severity of black Sigatoka, considering the border and central areas within the farms, in leaves 4 there were no statistical differences, only in the ‘‘Mega Impulso’’ farm there were statistical differences in leaf 5 between the two areas of application (table 2).

**Table 2. Effect of the fungicides evaluated on the severity of black Sigatoka on leaves 4 and 5, in plants of the central and border areas in three banana plantations of the Pasaje canton, Ecuador.**

| Farms | Severity (%) | |
|---|---|---|
| | Leaf 4 | Leaf 5 |
| "El Playon" L | 37.5aA | 55.0aA |
| "El Playon" C | 38.0a | 55.5a |
| "Mega Impulso" L | 42.5bB | 60.0bB |
| "Mega Impulso" C | 43.0b | 62.7c |
| "Lolita" L | 45.0cC | 72.5dC |
| "Lolita" C | 45.0c | 73.0d |

Note: The values with the same lowercase letter indicate that the means did not present significant differences within the farms, and the values with different capital letters indicate that there were differences between the farms. Abbreviations: L=Border; C=Center.

**Table 1. Rotations of fungicides used in the management of black Sigatoka in the three banana plantations of the Pasaje canton, Ecuador.**

| Farms | Fungicides (systemic) | | | | | |
|---|---|---|---|---|---|---|
| | Principal | Chemical group | Dose ($L.ha^{-1}$) | Mixer | Dose ($L.ha^{-1}$) | Chemical group |
| "El Playon" | T1. Epoxiconazole | Triazole | 1.25 | Tridemorph | 0.5 | Amine |
| | T2. Spiroxamine | Spiroketalamines | 0.4 | Pyrimethanil | 0.5 | Anilinopyrimidines |
| | T3. Difenoconazole | Triazole | 0.4 | Tridemorph | 0.5 | Amine |
| | T4. Fenpropimorph | Amine | 1.0 | Pyrimethanil | 0.5 | Anilinopyrimidines |
| "Mega Impulso" | T3. Difenoconazole | Triazole | 0.4 | Tridemorph | 0.5 | Amine |
| | T4. Fenpropimorph | Amine | 1.0 | Pyrimethanil | 0.5 | Anilinopyrimidines |
| | T1. Epoxiconazole | Triazole | 1.25 | Tridemorph | 0.5 | Amine |
| | T2. Spiroxamine | Spiroketalamines | 0.4 | Pyrimethanil | 0.5 | Anilinopyrimidines |
| "Lolita" | T2. Spiroxamine | Spiroketalamines | 0.4 | Pyrimethanil | 0.5 | Anilinopyrimidines |
| | T1. Epoxiconazole | Triazole | 1.25 | Tridemorph | 0.5 | Amine |
| | T4. Fenpropimorph | Amine | 1.0 | Pyrimethanil | 0.5 | Anilinopyrimidines |
| | T3. Difenoconazole | Triazole | 0.4 | Tridemorph | 0.5 | Amine |

Significant differences were found among the farms, the ANOVA allowed to differentiate the three subsets that were formed in "El Playón", "Mega Impulso" and "Lolita", in the border (L) and the center (C), which indicated that the fungicides and the application area had a different behavior (table 2). All systemic fungicides applied at a frequency of 14 calendar days exerted a satisfactory control (37.5 to 45 % severity) of the disease on leaf 4 in general, showing that the different treatments of fungicides acted independently in the different farms.

When the subsets between the border and central areas were analyzed (table 2), in the Mega Impulso farm, significant differences, in leaf 5, between the two zones (p = 0.001) were found. In relation to leaf 4 in the production units, "El Playón", in the border and central areas, the lowest percentages of severity were 37.5 and 38 %, respectively; values considered high according to the scale used by Cedeño-Zambrano *et al*. (2021), Sánchez *et al*. (2021) and Sánchez-Urdaneta *et al*. (2021).

In the border areas of the "Mega Impulso" and "Lolita" farms, the percentages of severity were also within the range considered high 42.5 and 45 %, respectively; which implied a greater risk of burning for these farms, highlighting that in the "Lolita" farm the severity in leaf 4 was the highest with 45 % in border area and 45.5 % in central area.

The lowest percentage of severity of the disease in leaf 5 was presented by "El Playón" farm, both for the central and border areas with 55.0 and 55.5 % (severe), respectively; the "Mega Impulso" farm showed an average of 60.0 % for the border and 62.7 % for the center (severe); which was statistically different. "Lolita" had a severity percentage of 72.5 % and 73.0 % (severe) for the border and central areas, respectively (table 2). The results showed that the systemic fungicides used in the research had different behaviors when evaluating the severity between farms (p = 0.001) for each application site in the treated leaves, which coincided with what was reported by Quevedo *et al.* (2018) who mentioned that when rotating systemic and protective fungicides, the analysis of variance of the evolutionary states (severity) showed statistical differences between farms.

The banana plantations of "El Playón", "Mega Impulso" and "Lolita" were areas planted with the Williams cultivar, and the treatments were applied according to the mixtures of systemic fungicides most used in La Peaña parish; triazole + amine, amine + anilinopyrimidines, difenoconazole + amine and spiroxamine + anilinopyrimidines (table 1). The results obtained in the control of black Sigatoka, confirmed that the rotation of the molecules is important for the timely control of the disease (Cedeño *et al*., 2017).

**Old leaves free of streaks (OLFS)**

The range of old leaves free of streaks ranged from 7 to 7.3 (figure 1). In "El Playón" farm the results of OLFS in both areas were the same in the treatments T3 = difenoconazole + tridemorph and T4 = fenpropimorph + pyrimethanil (figure 1), the highest values were obtained at the "Lolita" farm for T1 = epoxiconazole + tridemorph and T4 = fenpropimorph + pyrimethanil. What has been observed for OLFS in T4 can be justified since fenpropimorph is a systemic fungicide of triple action that has preventive and curative activity, and acts as a protectant, in addition its absorption medium is foliar and its mechanism of action lies in the inhibition of the germination of the spores of the fungus (Agroactivo, 2023).

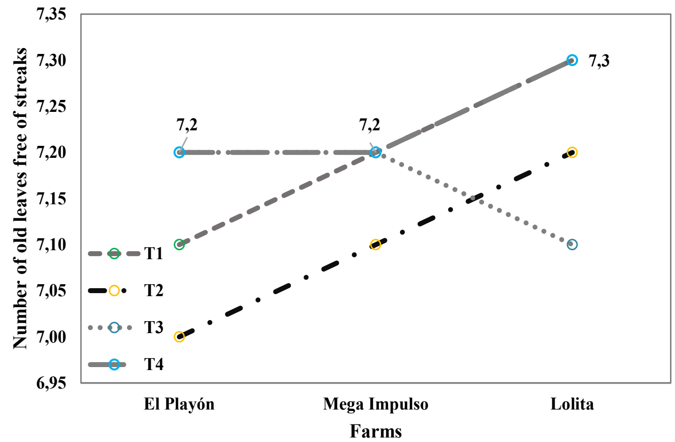


**Figure 1. Old leaves free of streaks (average) by treatment of fungicides applied at "El Playón", "Mega Impulso" and "Lolita" farms.** Abbreviations: T1= fungicide epoxiconazole + tridemorph, T2= spiroxamine + pyrimethanil, T3= difenoconazole + tridemorph and T4= fenpropimorph + pyrimethanil.

Figure 2 shows that the old leaves free of streaks in the central area, T1 = epoxiconaxole + tridemorph presented a higher value, and T2 = spiroxamine + *pyrimethanil (*6.95) presented lower values. This result was due to the fact that, at the time of the aerial spraying, the flight height was more efficient in the center of the plantation, because there was greater ease for the plane to pass closer to the foliage and its coverage was greater. For the border area, T2 spiroxamine + pyrimethanil was equal to T4 = fenpropimorph + pyrimethanil, with the lowest means for this variable being attributed to the difficulty of the plane to fly and avoid losses due to drifts (Arriaga-García *et al*., 2022).

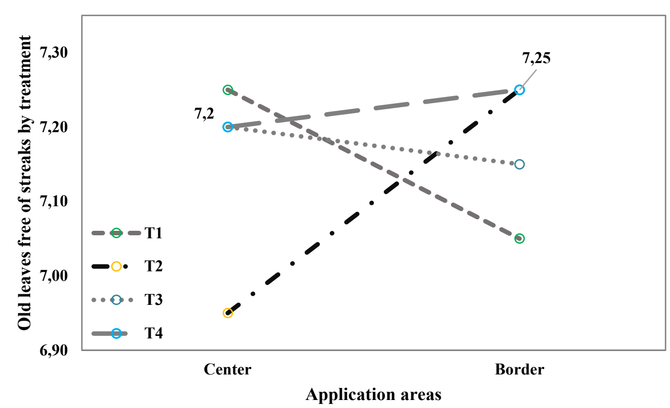


**Figure 2. Old leaves free of streaks (average) by areas of (average) by areas of application and by treatment of fungicides evaluated at "El Playón", "Mega Impulso", and "Lolita" farms.** Abbreviations: T1= fungicide epoxiconazole + tridemorph, T2= spiroxamine + pyrimethanil, T3= difenoconazole + tridemorph, and T4= fenpropimorph + pyrimethanil.

**Functional leaves**

Figure 3 shows that at "El Playón" farm for treatments (T3 and T4) 12.3 functional leaves were quantified, while for T3 and T4 at the "Mega Impulso" farm there were 12.0 and 12.7 total functional leaves on average, respectively, showing a difference of 0.7 leaves for this particular mixture. At the "Lolita" farm, 12.3 and 12 total functional leaves were reported for T3 and T4, respectively. Likewise, T1 (epoxiconazole + tridemorph) and T2 (spiroxamine + pyrimethanil) had similar behavior, only to a greater extent in T1.

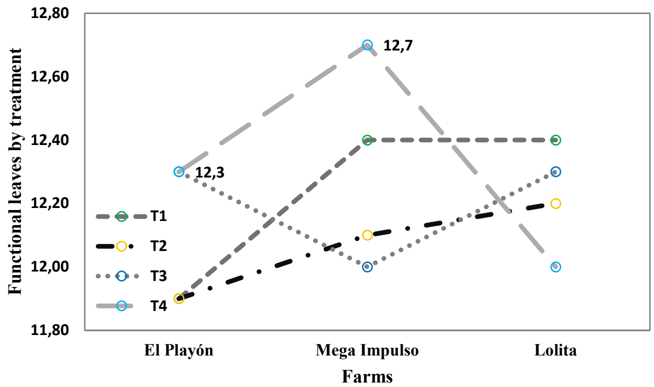


**Figure 3. Functional leaves (average) by treatment of fungicides applied at "El Playón", "Mega Impulso", and "Lolita" farms.** Abbreviations: T1= epoxiconazole fungicide + tridemorph, T2 = spiroxamine + pyrimethanil, T3 = difenoconazole + tridemorph and T4 = fenpropimorph + pyrimethanil.

Hernández *et al*. (2016) pointed out that *M. fijiensis*, caused necrosis in the leaves and that this disease is endemic in the Musaceae and with recurrence both in dry and rainy season, they also mentioned that all phytosanitary programs should be reinforced with good defoliation management, eliminating the necrotic parts and with this, the frequencies of application decreased.

T1 = spiroxamine + pyrimethanil and T3 = difenoconazole + tridemorph, were the best treatments and presented equal values 12.45 of functional leaves for both the central and border areas (figure 4). The application of spiroxamine + pyrimethanil (T2) the average of the total leaves was 12.05 both in the area of application of the center and the border; with the use of fenpropimorph + pyrimethanil (T4) the average was 12.35 HF, which was 0.35 times higher than T4, with respect to T2, which shows that the mixtures fenpropimorph + pyrimethanil, acted in a preventive and curative way against black Sigatoka, guaranteeing 35 % more leaf area.

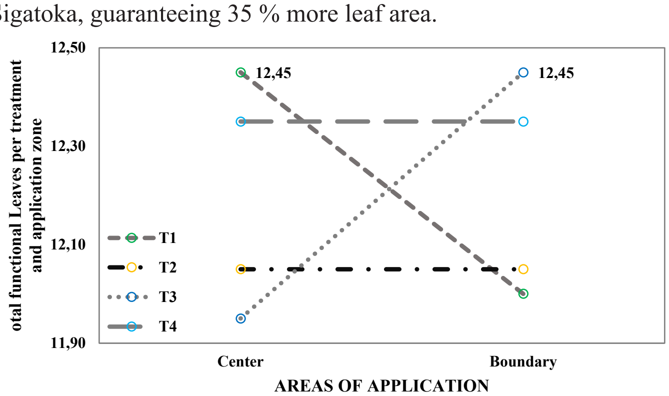


**Figure 4. Functional leaves (average) by application areas and by fungicide treatment evaluated at "El Playón", "Mega Impulso", and "Lolita" farms.** Abbreviations: T1= fungicide epoxiconazole + tridemorph, T2= spiroxamine + pyrimethanil, T3= difenoconazole + tridemorph and T4= fenpropimorph + pyrimethanil.

For the management of *M. fijiensis*, the most used fungicides have been of systemic action such as triazoles, strobirulins and anilinopyrimidines, which coincided with what was indicated by Martínez-Bolaños *et al*. (2012). Also highlighting what was reported by Mena-Espino and Couoh-Uicab (2015) who mentioned that 10 to 45 applications of fungicides per year were required for the chemical management of black Sigatoka, which agreed with the results of this study. It should be noted that authors such as Archicanoy (2001), and Barrera *et al*. (2016) indicated that applications in mixture of fungicides at the time of higher pressure of the disease should be preventive at short frequency, which allows efficient management of the disease. Where in addition, they suggested managing the crop using different levels of shade in order to reduce the effects of the disease, this could also be seen in the results obtained in this research in relation to the period of application of fungicides.

## Conclusions

It is necessary to use systemic fungicides for good management of black Sigatoka in banana cultivation, especially at the beginning of the rains, demonstrated through the fact that the fungicides used exerted a satisfactory control of black Sigatoka, in reference to the low percentages of severity of the disease presented in banana plants and the amount in general of functional leaves at the time of emission of the inflorescence (inflorescence-raceme) both for the central and border areas, particularly at "El Playón" and "Mega Impulso" farms.

The fungicides were applied in mixtures at a short frequency of 14 days of rotation, completing a total program of 28 cycles per year. In general, the phytosanitary control for the parameters total leaves, and old leaves free of streaks was within the normal ranges of a plantation with conventional management (chemical controls).

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