Effects of Different Rootstocks on Plant Growth, Development and Yield of Grafted Tomato (*Lycopersicon esculentum* Mill.)

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Abstract

This study was undertaken at the Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University from 2014 to 2016 to evaluate the effects of different rootstocks on the performance of grafted tomato and to determine the suitable rootstock for tomato production. Three rootstocks of local varieties: eggplant (Khayan pa dae tha - ခရမ်းပဒေသာ), tomato (Kyaught Me Gaung Sein- ကျောက်မဲခေါင်းစိမ်း) and hot pepper (Yemethin Moe Htaung- ရမည်းသင်းမိုးထောင်) were grafted with commercial tomato cultivar (Platinum 701). Results indicated that all tested local type rootstocks are suitable for tomato production since the grafting success rate is over 70%. Leaf emergence rate (Plastochron day^{-1}) was faster and plants were taller in the grafted plants than non-grafted plants. Increased photosynthesis efficiency with higher chlorophyll content leads to enhanced plant growth and reproductive developments of the grafted tomato (0.81 and 58.7) compared with the non-grafted tomato (0.75 and 52.3). Marketable yields were also higher in the grafted tomato (4146.1 g plant^{-1}) than non-grafted tomato (2491.7 g plant^{-1}). Among the grafted plants, those on eggplant rootstock produced the highest marketable fruit yield (5071.4g plant^{-1}) followed by the ones on local tomato rootstock (3894.3 g plant^{-1}) and local hot pepper rootstock (3472.6 g plant^{-1}). Non-grafted plants showed the lowest marketable yield (2491.7g plant^{-1}). These results suggested that grafting on suitable rootstock has positive effects on plant growth and fruit yield of tomato and local eggplant rootstock was the most suitable for tomato grafting.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is one of the most economically important vegetable crops and widely cultivated in the world. World production of fresh tomato for 2012 was about 161.8 million tons planted on 4.8 million hectares in 144 countries (FAOSTAT 2012) valuing at 58 billion dollars as the eighth most valuable agricultural product worldwide. Tomato is consumed as fresh, cooked or processed into various products such as tomato paste (puree), sauce, juice, canned and dried tomatoes. It contributes to a healthy, well-balanced diet, as it is rich in vitamins A and C, iron, phosphorus, amino acids, sugars and dietary fibers. However, tomato is susceptible to numerous soil-borne diseases and abiotic stresses, which cause significant losses in fruit yield every year (Rivard and Louws 2008). There are different ways to prevent soil-borne diseases such as crop rotation, breeding programs and the use of soil fumigants (Rivero et al. 2003; Yetisir and Sari 2003). Overuse of chemicals not only contaminates the food but also pollutes the environment. Furthermore, in controlling tomato diseases, there are some problems such as no chemicals available for bacterial wilt, crop rotation not feasible in practical life, to develop new cultivars very time-consuming and new cultivars becoming susceptible to new races of pathogens. Therefore, grafting vegetables is becoming popular not only to control soil-borne diseases but also create a higher tolerance to abiotic soil stresses (Rivero et al. 2003). It is a common practice to control soil-borne pathogens, especially for the cultivation of cucumber, melon, watermelon, tomato, pepper and eggplant in greenhouses in Japan, Korea, China and some other Asian and European countries (Lee 1994; King et al. 2008).

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Grafting enhances tolerance to abiotic stresses, increases yield, and results in more efficient water and nutrient use; extend harvest periods, and improves fruit yield and quality (Oda 2002; Lee and Oda 2003; Rivero et al. 2003). Rootstocks are selected for their ability to resist infection of certain soil-borne pathogens or their ability to increase vigor and fruit yield. The use of rootstocks offers many potential benefits, such as resistance to a wide range of pathogens in the soil, resistance to abiotic stress, and increased yield and fruit quality.

Currently, Myanmar tomato farmers are facing problems due to the climate change which might lead to the outbreak of pests and diseases, physiological disorder, flooding, drought and heat stress. Grafting on the rootstocks with desirable traits is one of the solution methods to overcome these problems of tomato. However, limited information on rootstock varieties and their combinations with commercially available scions is currently a major barrier to the wider application of grafting in commercial tomato production in Myanmar. Thus selection of proper scion and rootstock is a key factor for higher fruit yield and good quality of crops.

Therefore, the experiment was carried out with the following objectives:

(1) To evaluate the effects of different rootstocks on plant growth, development and fruit yield of grafted tomato
(2) To determine the suitable rootstock for tomato production

Materials and Methods

This experiment was conducted at the Department of Horticulture and Agricultural Biotechnology, Yezin Agricultural University from 2014 to 2016 using Randomized Complete Block Design (RCBD) with four replications. Three different types of local cultivars: (Khayan pa dae tha - ခရမ်းပဒေသာ), tomato (Kyaught Me Gaung Sein- - ကျောက်မဲခေါင်းစိမ်း) and hot pepper (Yemethin Moe Htaung- - ရမည်းသင်းမိုးထောင်) were used as stock plants and commercial tomato cultivar (Platinum 701) as scion.

1. Procedures of grafting

Wedge and cleft grafting was used in all experiments because it is the most commonly used method for Solanaceous crops (Lee and Oda 2003). Razor blades and rubber tubes were used to perform the grafting. The procedures of grafting are as follows:

Stage 1: The rootstock was cut off just below the cotyledon using a razor blade.
Stage 2:The longitudinal cut was prepared about 1.5 cm deep from the top.
Stage 3: The scion was pruned to 1-2 leaves and the lower end of the stem was prepared into a tapered wedge the same size with cleft incision of the rootstock.
Stage 4: The rubber tube was put to the stock portion in order to hold the scion tightly and thus improve stability.
Stage 5: The scion was inserted into the cleft of the stock by holding with a rubber tube the same as a bicycle valve tube (Plate 1).

Grafting was carried out in a shady place to avoid wilting of the grafted plants. After grafting, as indicated by Marsic and Osvald (2004), the grafted plants were kept in the chamber maintained at 28–30°C with more than 95% relative humidity for three days to get better healing and enhance the survival rate. A healing chamber was constructed with bamboo to form a dome. The first layer of the whole dome was covered with clear plastic and the second layer was with green net. High relative humidity was maintained by spraying with water around the roof and grafted plants three times daily. Seven days after grafting, the green net and plastic cover were gradually removed in order to increase light intensity and reduce the humidity. Successful grafted plants were transplanted to the plastic bags and they were kept in the nursery. The grafted tomato seedlings were nursed in the nursery for one week before transferring to the field. The seedlings were thoroughly watered before transplanting to the field. The plants were transplanted to the well prepared field directly in Experiment III.

2. Field management practices

Triple super phosphate (P_2O_5) and poultry manure were applied at the rate of 100 kg ha^{-1} and

20 t ha^{-1} respectively during land preparation. Furadan was used to control insects while preparing the land. Just after transplanting, tomato plants were watered daily for a week until they had recovered. After that, watering was done as necessary. Weeding was carried out regularly, 1 or 2 days before every fertilizer application as side dressing. The recommended rate of the compound fertilizer was applied 5 times at 10- days intervals after transplanting. Foliar fertilizer (Comet Plus) was applied weekly starting from flowering stage to harvest.

Pests and diseases were controlled by alternate application of recommended chemicals (Daconil, Topsim and Mangozeb). The plants were supported by bamboo sticks to keep the tomato vines upright. The main tomato stems were loosely tied to the sticks with the strings.

3. Data collection and calculation

The data were collected from five randomly selected plants in each plot. Data collection was started one week after transplanting till harvest. The graft success rate was evaluated three days after grafting. Plant height, stem diameter, number of leaves, leaf emergence rate, number of branches per plant, number of days to 1st flowering, number of trusses per plant, number of flowers per truss and fruit setting percent were recorded throughout the experiment. At the time of harvest, final plant height, number of days to harvest, number of fruits per plant, single fruit weight, fruit diameter and total fruit yield were collected.

Graft success rate (%) was recorded three days after grafting. It was calculated by the following formula.

$$\text{Graft success rate} = \frac{\text{Number of success plants}}{\text{total plants}} \times 100$$

Field survival rate (%) was evaluated on seven days after transplanting. It was calculated by the following formula.

$$\text{Field survival rate} = \frac{\text{Number of survival plants}}{\text{total plants}} \times 100$$

Leaf emergence rate was noted by measuring the youngest leaf (<2cm).It was calculated by the following formula (Erickson and Michelini 1957).

$$PI = n + \frac{\text{Log Ln} - \text{Log R}}{\text{Log Ln} - \text{Lgo Ln} + 1}$$

PI = Plastochron index

n = The serial number, counting from the base, of that leaf longer than reference leaf

Ln = Leaf length that is greater than the refer

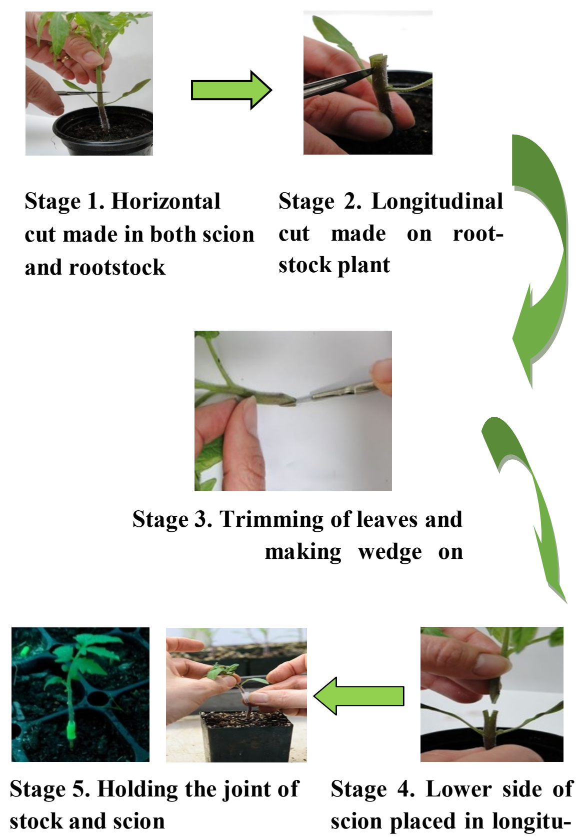

Plate 1. Stages of cleft grafting method in tomato grafting

ence leaf (R)

R = Length of the reference leaf (e.g. 10 mm)

Ln + 1 = The length of the leaf that is younger than leaf (Ln)

Chlorophyll content was measured by SPAD meter. The *SPAD*-502 Plus determined the *chlorophyll concentration* by *measuring* the leaf absorbance in red and near-infrared regions. Photosynthesis efficiency was measured using Fluoro Pen FP 100 meter. Selected fully developed youngest leaves from the sample plants were dark-adapted for 30 minutes before starting the measurements using leaf clips provided by the manufacturer.

4. Statistical analysis

Analysis of variance was calculated by using SAS 9.1. Mean comparison was performed with the least significant difference (LSD) at 5 % level.

Results and Discussion

Graft success rate and field survival rate (%):

The graft success rate and field survival rate are presented in Table 1. The graft success rate ranged from 70 to 90% indicating that the type of rootstock has an influence on the graft success percent. The highest graft percent by local eggplant rootstock (87.3 %) among the other rootstocks depicted eggplant is that with good compatibility during healing period. Many other factors influence the grafting success, including post-grafting environmental conditions, plant vigor, carbohydrate content, and the proper match of vascular bundles (Bisognin et al. 2005).

The numbers of plants survived in the field were determined seven days after transplanting. Among the rootstocks, plants on eggplant rootstock showed maximum field survival rate (92.7%), and plant on hot pepper rootstock showed the lowest field survival rate (79.8%). Highest field survival rate in eggplant rootstock revealed that it is more tolerant to biotic and abiotic stresses than the other two rootstocks. However, as all the three rootstocks showed over 70 % of graft success and field survival rate, they all can be used as suitable rootstocks in

Table 1. Comparison of graft success rate and field survival rate among the rootstocks

Rootstock type	Graft success rate (%)	Field survival rate (%)
Eggplant	87.3	92.7
Tomato	80.3	89.5
Hot pepper	70.7	79.8
Non-grafted	-	74.5

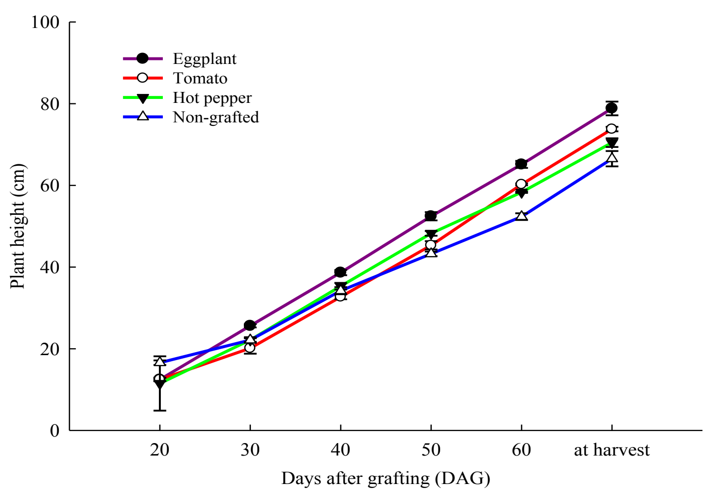

Figure 1. Effect of different rootstocks on plant height of grafted tomato

Table 2. Effect of different rootstocks on leaf emergence rate, *chlorophyll content and photosynthesis efficiency* of

Rootstock Type	Plastochron day^{-1}	Photosynthesis efficiency	Chlorophyll content
Eggplant	0.33 a	0.83 a	59.4 a
Tomato	0.29 b	0.79 b	58.5 a
Hot pepper	0.28 b	0.81 ab	58.3 a
Non-grafted	0.19 c	0.76 c	52.3 b
Pr>F	**	**	**
$LSD_{(0.05)}$	0.02	0.02	2.81
Contrast analysis of grafted vs. non-grafted			
Grafted	0.27	0.81	58.72
Non-grafted	0.19	0.75	52.34
Pr>F	**	**	**

Means in the same column followed by the same letter are not significantly different at P≤0.05

* = Significant at P≤0.05 ** = Highly significant at P≤ 0.01 ns = Not significant

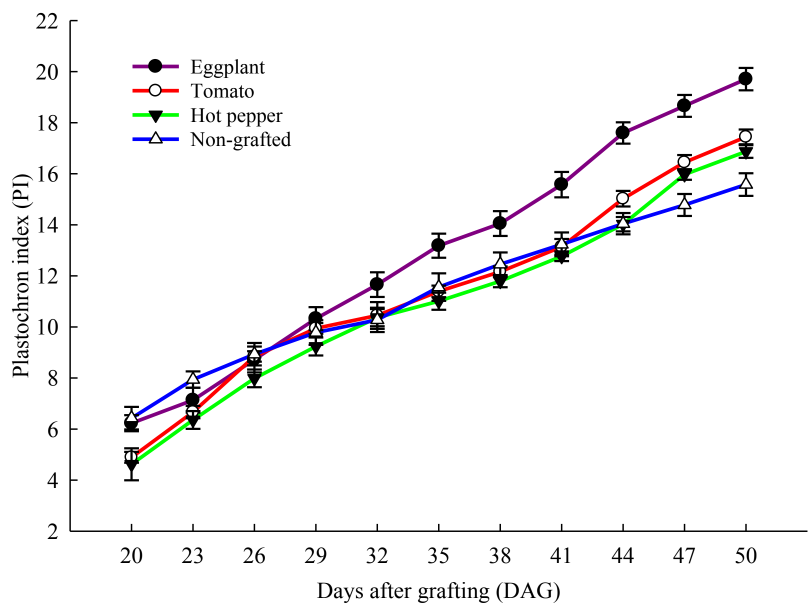

Figure 2. Effect of different rootstocks on plastochron index (PI) of grafted tomato

producing grafted tomato plants for commercial production.

Plant height: Plant height was significantly different as affected by rootstock (Figure 1). At 20 DAG (Days after grafting), the plant height of non-grafted tomato was significantly higher than all grafted tomatoes. Starting from 40 DAG, plants on eggplant rootstock were significantly taller than non -grafted and other rootstock plants. At harvest, the plants on eggplant rootstock were the tallest (79 cm), followed by tomato rootstock (74 cm), hot pepper rootstock (71 cm) and non-grafted tomato (67 cm). These data indicated that the type of stock has a strong influence on plant height of grafted tomato. Shorter plant height of grafted plants at an early growth stage (20 DAG) is probably due to the grafting stress. The tallest height of grafted tomatoes on eggplant rootstock from 40 DAG to final harvest could be due to vigorous plant growth of local eggplant rootstock. Bletios (2006) also highlighted that local eggplant type (*Solanum torvum*) rootstock was very vigorous as measured by plant height, stem diameter and root biomass and thus its vigorous root system are often capable of absorbing water and plant nutrients more efficiently than self-rooted scion plants.

Shoot growth (Plastochron index): Shoot growth was measured by Plastochron Index (PI) (Figure 2). Significant difference of Plastochron Index was observed. Starting from 32 DAG, Plastochron Index of grafted tomato on eggplant rootstock was significantly higher than the others. At 50 DAG, The highest Plastochron Index was observed in the eggplant rootstock (17.2) followed by tomato rootstock (16.4) and hot pepper rootstock (15.9). The minimum Plastochron Index was observed in the non-grafted tomato (13.6). This data highlighted that the Plastochron Index of grafted tomato was more vigorous than that of the non-grafted tomato. Among the grafted plants, Plastochron Index of the grafted tomato varies depending on the type of rootstock. This could be due to the variation of rootstock vigour, root system and their uptake ability of water and nutrients. The strongest grafted plant observed in eggplant rootstock could be due to the vigorous growth of eggplant rootstock as described by highest leaf emergence rate (Plastochron day^{-1}) of eggplant rootstock among the others.

Leaf emergence rate (Plastochron day^{-1}): Effect of different rootstocks on leaf emergence rate of grafted and non-grafted tomato is described in Table 2. Leaf emergence rate was measured by Plastochron day^{-1}. Leaf emergence rate of grafted tomato (0.27) was significantly higher than that of non-grafted tomato (0.19). Among the rootstock, grafted tomato on eggplant rootstock showed the maximum leaf emergence rate (0.33) followed by tomato (0.29) and hot pepper rootstock (0.28). The result showed that the leaf emergence rate of all grafted plants was significantly higher than the non-grafted ones. It may be due to vigorous growth of rootstocks. Eggplant rootstock showed the maximum leaf emergence rate in all experiments suggesting that eggplant rootstock was the most vigorous one among the rootstocks.

Chlorophyll content and photosynthesis efficiency: Chlorophyll content and photosynthesis efficiency of grafted and non-grafted tomato are described in Table 2. Chlorophyll content of grafted plants was significantly higher than that of non-grafted ones. However, there was no significant difference among the rootstocks. Significantly higher value of chlorophyll content of grafted plants than those of non-grafted ones influenced on the photosynthesis efficiency of the plants. Photosynthesis efficiency was significantly different between the grafted and non-grafted tomatoes. Among the treatments, the highest photosynthesis efficiency was observed in grafted tomato on eggplant rootstock (0.83) followed by hot pepper rootstock (0.81) and tomato rootstock (0.79) while non-grafted tomato showed the lowest value (0.76). It can be said that the photosynthesis efficiency varies depending on the type of rootstocks. This could be due to the vigorous plant growth in line with higher chlorophyll content of the grafted plants. These results are in agreement with those of Zheng et al. (2009), who found that grafting reduced damage to the photosynthetic apparatus, since this maintained higher photochemical activity of Photosystem II (He et al. 2009). Bhatt et al. (2015) also showed the increased photosynthesis efficiency in eggplant rootstock even under stress condition.

Number of days to 1st harvesting: The number of days taken to 1st harvesting was significantly affected by the use of rootstocks. The earliest 1st harvesting was observed in grafted tomato on eggplant rootstock (85 days) followed by hot pepper rootstock (88 days) and tomato rootstock (90 days). The latest 1st harvesting was found in non- grafted tomato (96 days). This data showed that grafted plants on eggplant rootstock showed the earliest production of tomato fruits among the treatments. Similar results were reported by other researchers (Bletsos.2005; Khah et al. 2006, Voutsela et al. 2012), who showed that marketable fruit yield of grafted tomato plants was significantly higher than those of self-rooted

Table 3. Comparison of yield and yield components of grafted and non-grafted plants as affected by dif

Rootstock type	Days to 1st harvesting	No. of fruits $plant^{-1}$	Single fruit weight(g)	Fruit diameter (cm)	Fruit yield $plant^{-1}$(g)
Eggplant	85.3 d	91 a	62 a	4.5 a	5071.4 a
Tomato	90.1 b	75 b	60 ab	4.4 ab	3894.3 b
Hot pepper	87.9 c	73 bc	55 b	4.4 ab	3472.6 b
Non-grafted	95.9 a	62 c	48 c	4.3 b	2491.7 c
Pr>F	**	**	**	ns	**
$LSD_{(0.05)}$	1.7	11.5	4.8	0.2	0.7
CV (%)	1.2	9.9	5.5	3.2	12.6
Contrast analysis of grafted vs. non-grafted					
Grafted	87.8	80	59	4.4	4146.1
Non-grafted	95.9	62	48	4.3	2491.7
Pr>F	**	**	**	ns	**

Means in the same column followed by the same letter are not significantly different at P≤0.05

ones.

Number of fruits, single fruit weight and fruit diameter: Significant difference in the number of fruits *per plant* was noted between the grafted and non-grafted plants (Table 3). The number of fruits of grafted tomato was significantly higher than that of non-grafted tomato. Among the treatments, grafted tomato on eggplant rootstock resulted in the highest number of fruits (91) followed by tomato rootstock (75), hot pepper rootstock (73) and non-grafted tomato (62) respectively. Fruit weight was also significantly affected by rootstocks. The highest fruit weight was observed in the grafted tomato onto eggplant rootstock (62 g) followed by tomato rootstock (60 g), hot pepper rootstock (55 g) and the non-grafted tomato (48 g). The diameters of fruits were significantly different among the treatments. Fruit diameter of non-grafted tomato was smaller than that of grafted tomato. Grafted tomato on eggplant rootstock had maximum fruit diameter (4.5 cm) and non-grafted tomato had minimum fruit diameter (4.3 cm). In all experiments, the maximum fruit weight and fruit diameter were obtained by local eggplant rootstocks. These data highlighted the type of rootstock has an influence on fruit size of grafted tomato. Similar findings of increasing fruit size in grafted watermelon (Miguel et al. 2004) and eggplant (Passam et al. 2005) were also observed. In a similar study, fruit weight of grafted tomato plants was found to be higher than that of non-grafted plants (Khah et al. 2006).

Fruit yield per plant: Fruit yield of grafted tomato as affected by different rootstocks is shown in Table 3. The fruit yield of grafted plant was significantly higher than the non-grafted ones. The greatest total fruit yield was achieved from grafted tomato on eggplant rootstock (5071.4 g) followed by tomato rootstock (3894.3 g), hot pepper rootstock (3472.6 g), and non- grafted tomato (2491.7 g). Differences in fruit yield in accordance with the type of rootstock indicated the impacts of rootstock on fruit yield of grafted tomato. Maximum fruit yield obtained from eggplant rootstock in all experiments is likely due to eggplant being more vigorous. Schwarz et al. (2010) also found that eggplant is very effective in water uptake than tomato root systems. Similar yield increase in grafted tomato and cucurbits have been reported by other researchers (Lee and Oda 2003; Chung and Lee 2007; Leonardi and Giuffrida 2006; Proietti et al. 2008).These data suggested that grafted tomato has a positive and improved effect on plant growth, development and fruit yield.

Conclusion

The results indicated that grafted tomato has a great influence on photosynthesis efficiency, plant growth and fruit yield. Grafted plants showed faster leaf emergence and greater shoot growth leading to greater plant growth and development. Grafted plants are taller than non-grafted plants. Grafted plants also result in earlier reproductive development, faster flowering, earlier harvesting and higher fruit yield compared to non-grafted plants. Therefore, tomato grafting has positive effects on plant growth and development, fruit yield and earliness.

The type of rootstock also has a positive effect on chlorophyll content enhancing photosynthesis efficiency. Local types of rootstocks of eggplant, tomato and hot pepper are feasible rootstocks for tomato grafting. Among the rootstocks, eggplant rootstock showed the best performance in terms of graft success percent, field survival rate, plant growth as well as higher fruit yield and earlier harvest. Therefore, local eggplant can be used as rootstock in tomato production.

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