Studies to Evaluate Hydroponic Culture of Teak Seedlings in a Temperate Greenhouse

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Abstract

Teak (*Tectona grandis* L.f.) is one of the premier timber species globally. High demand, combined with harvesting restrictions across its natural range, has resulted in extensive plantation establishment. Plantations, in turn, depend on the production of healthy seedlings for successful establishment. As a lead up to assist growers in diagnosing seedling nutrient issues, we conducted a series of studies to test the feasibility of growing teak seedlings hydroponically in temperate greenhouses. Teak seedling studies were conducted in both sand and liquid culture hydroponic systems. Within each system, different strength nutrient solutions, solution pH levels, and pH buffers were tested to determine optimal conditions for growing seedlings. These studies indicated that teak seedlings could be successfully grown hydroponically in temperate greenhouses and responded best to a full-strength nutrient solution with a pH of 5.8 and a sodium hydroxide buffer. These results will be useful for conducting future studies to evaluate nutrient disorders in teak seedlings.

Introduction

Teak (*Tectona grandis* L.f.) is one of three species in the *Tectona* genus (others include *T. hamiltoniana* and *T. phillipensis*) within the Verbanaceae family. Of the three, *T. grandis* is the most highly valued and is considered to be one of the premier timber species in the world. High levels of resistance to insect damage and water-related decay coupled with a combination of durability, strength, workability, and aesthetically pleasing color result in this valuation.

Within India, high demand for teakwood has resulted in prices ranging from US$225 to $900 per m^3 for plantation grown logs (ITTO 2017, Thulasidas 2013) while in the United States, values as high as US$4,000 per m^3 have been reported for quality logs (Ladrach 2009).

Appetite for teak lumber, coupled with restrictions on harvesting from natural stands in its native southeastern Asia, has resulted in numerous plantations being established throughout the tropics. In the Americas, the first reported plantation was in Trinidad in 1913 (Keogh 1979). In Puerto Rico and the U.S. Virgin Island of St. Croix, approximately 130 ha have been established (Weaver 1993). As of 2010, teak plantations were reported to have been planted in 65 countries, making up an estimated 75 percent of the world's high-quality, tropical hardwood plantations (Koskela et al. 2014).

While there is a considerable body of literature on teak under natural and plantation conditions, the amount of information pertaining to the production of seedlings is modest (Swaminathan and Srinivasan 2004). Furthermore, even less research has been done on the nutrient requirements of teak seedlings. To date, no single study has examined the 12 essential micro- and macronutrients and how they each impact the growth of teak seedlings. One of the best ways to study plant nutrients is with hydroponic culture.

Crop production in soilless culture systems requires an adequate supply of all the elements essential for plant growth in the nutrient solution (Kilnic et al. 2007). A nutrient solution for hydroponic systems is an aqueous solution containing mainly inorganic ions from soluble salts of essential elements for higher plants (Trejo-Téllez and Gómez-Merino 2012). Most modern hydroponic nutrient solutions are based on the work of Hoagland and Arnon (1950) and have been adapted to numerous crops (Whipker 1988). Plants have marked powers of adaptation to different nutrient conditions (Hoagland and Arnon 1950). Nonetheless, it is important to determine suitable nutrient solutions for each plant species (Kilnic et al. 2007).

In addition to determining the nutrient solution composition, one needs to consider the solution strength. Several studies have found that reducing solution strength had no significant impact on fruit production. Kane et al. (2005) found that biomass production of onion was as great in half-strength Hoagland's as in the more concentrated solution. Siddiqui (1998) found a 25-percent strength solution did not decrease tomato fruit yield.

As plants grow, they absorb minerals, which alters nutrient levels, and oftentimes pH, in the solution. Periodic replacement of all or a portion of the nutrient solution helps to replace lost nutrients and maintain consistency in nutrient concentrations. In general, the recommended pH for hydroponic culture is 5.5 to 5.8 to optimize overall nutrient availability (Bugbee 2004). Suitable teak soils are sandy and slightly clayey, fertile, deep, and well-drained, with a neutral or slightly acid pH (DeCamino et al. 2002). In hydroponic systems, pH is constantly changing as plants grow and take up nutrients (Berry and Knight 1997). Once a species-specific pH level has been targeted for nutrient solutions, maintaining this pH can be achieved by adding acids or bases to lower or raise the pH, respectively. In choosing a buffer, care must be taken to utilize one that does not alter the nutrient solution composition. Two commonly used pH buffers are calcium hydroxide and sodium hydroxide. The use of calcium hydroxide for growing teak is attractive, as teak has a noted calcium demand. Unfortunately, however, calcium hydroxide tends to precipitate out of solution and can clog the fine tubing used in automated delivery systems (Saravitz 2013).

A series of studies was conducted to investigate the feasibility of growing teak hydroponically in a temperate greenhouse. Specifically, these studies addressed the following questions: (1) How do teak seedlings respond to both sand and liquid culture hydroponic systems? (2) What nutrient solution concentration is optimum for growing teak seedlings? (3) What is the associated pH of the optimum nutrient solution? And, (4) what is the recommended pH buffer for use in the liquid culture hydroponic system? The results from this study will be useful for future studies of teak seedling nutrition.

Nutrient Solution Strength Study

Materials and Methods

During the summer of 2013, teak seedlings were grown in a sand culture hydroponic system with three nutrient solution treatments in a greenhouse located in Raleigh, NC (35.8° N, 78.7°W). Greenhouse conditions during the study were night/day temperatures of 21 ºC/18 ºC with ambient light and natural photoperiod.

Following a 24-hour room temperature water stratification, seeds were sown directly into 72-cell germination trays (4.0 by 4.0 by 5.8 cm cell dimensions) filled with a sterile peat and perlite medium (figure 1). After 34 days, seedlings were transplanted into 14-cm deep plastic pots filled with acid-washed silica sand. In transplanting, efforts were made to retain the entire root system. Eighteen seedlings were transplanted into three different nutrient concentration treatments for a total of six seedlings per treatment. Seedling pots were placed into three separate lengths of polyvinyl chloride (PVC) irrigation pipe (1.8 m long and 10.2 cm diameter) fitted with six PVC funnels placed into openings in the pipe (figure 2). Each pot had two drip irrigators placed on opposite sides of the stem with flow oriented toward the plant (figure 3). Daily irrigation occurred once every 3 hours from 0600 to 1800. Irrigation was automated and pumped through the system using sump pumps placed in 19-L buckets located below the seedlings. The nutrient solution used in irrigation drained from the bottom of each pot into the sloped PVC pipe. Used solution was captured and recirculated throughout the system. Nutrient solutions were changed weekly to replace nutrients taken up by the plants. Plants were monitored daily for

Figure 1. Recently germinated teak seedlings. (Photo by Andrew Whittier, 2013)

Figure 2. Sand culture hydroponic system. (Photo by Andrew Whittier, 2013)

Figure 3. Recently transplanted teak germinant in sand culture hydroponic system. (Photo by Andrew Whittier, 2013)

nutrient solution response and measured for height and basal diameter weekly for 5 weeks.

Treatments began immediately after transplanting into pots and consisted of 10-, 50-, or 100-percent concentration of a complete modified Hoagland's all-nitrate nutrient solution (Hoagland and Arnon 1950). The full-strength stock solution was mixed with deionized (DI) water to a total volume of 100 L (table 1). The 100-percent solution consisted of only premixed solution, the 50-percent solution was a 1:1 mix of the full-strength solution and DI water, and the 10-percent solution was 1:9 ratio of full-strength solution to DI water. Growth means were analyzed using PROC ANOVA of the Statistical Analysis System software package (SAS 1988).

Figure 4. Ten percent strength nutrient solution seedling at 30 days. (Photo by Andrew Whittier, 2013)

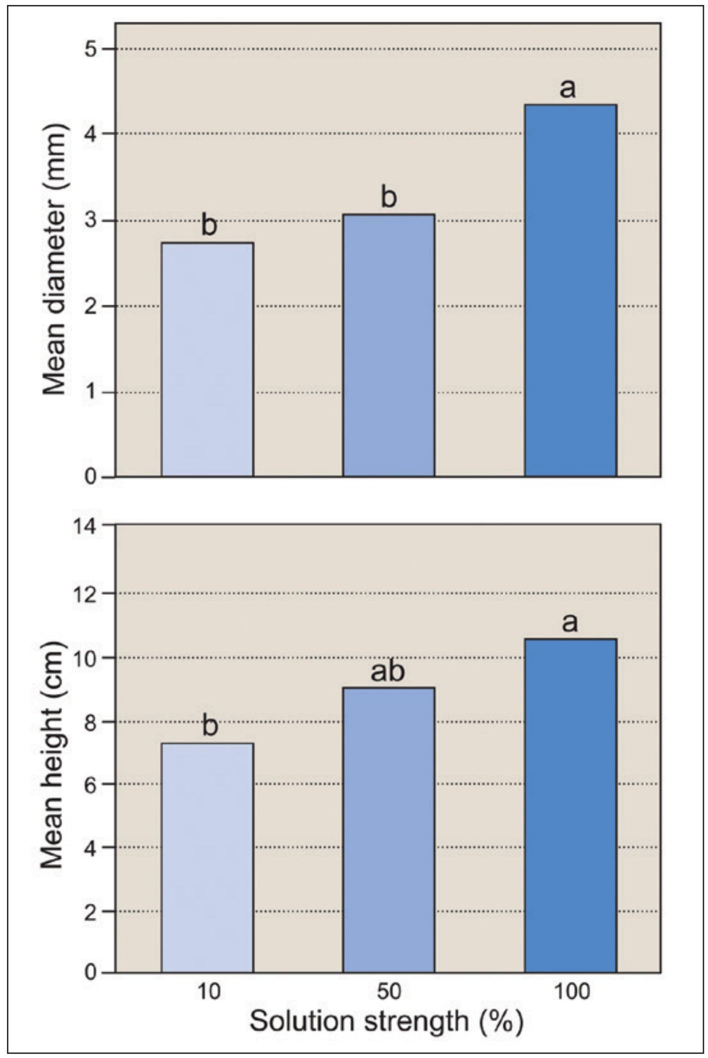

Figure 5. Teak seedling basal diameter and height at week five by solution strength in sand culture. Bars with the same letter are not significantly different at the $P \leq 0.05$ level.

Results

After 5 weeks, basal diameter and height of teak seedlings grown in the 100-percent solution were significantly larger than those grown in the lower-strength solutions (figures 4 and 5). None of the 18 seedlings in any of the three solution strengths died over the 5-week period. This study indicates that teak seedlings will

Table 1. Salts and bases used to formulate nutrient solutions based on Hoaglund and Arnon (1950). Salts and bases were added (mL/100L solution) to deionized water to make 100L of each solution.

Fertilizer salt and base	Stock solution molarity	100% solution	50% solution	10% solution
Potassium nitrate (KNO_3)	1M	500	250	50
Calcium nitrate tetrahydrate [$Ca(NO_3)_2 \bullet 4H_2O$]	1M	500	250	50
Potassium phosphate monobasic (KH_2PO_4)	1M	100	50	10
Magnesium sulfate heptahydrate ($MgSO_4 \bullet 7H_2O$)	1M	200	100	200
Iron diethylenetriam-epentaacetic acid (FeDTPA)	1M	100	50	10
Manganese chloride tetrahydrate ($MnCl_2 \bullet 4H_2O$)	20 mM	90	45	9
Zinc chloride ($ZnCl_2$)	20 mM	15	7.5	1.5
Cupric chloride dihydrate ($CuCl_2 \bullet 2H_2O$)	20 mM	15	7.5	1.5
Boric acid (H_3BO_3)	100 mM	45	22.5	4.5
Sodium molybdate dihydrate ($Na_2MoO_4 \bullet 2H_2O$)	1 mM	10	5	1
Sodium hydroxide (NaOH)	1 M	40	20	4

grow suitably in a sand culture hydroponic system under varying concentrations of a complete modified Hoagland's all-nitrate solution. Based on these findings, the full-strength solution was deemed optimum for subsequent teak nutrient experiments.

Hydroponics Solution pH Study

Materials and Methods

To fine-tune hydroponic conditions for growing teak seedlings, three nutrient solution pH levels were examined in a liquid culture hydroponic system at North Carolina State University Phytotron (Raleigh, NC). Seeds were soaked in water for 24 hours, then sown into 164 ml3 Ray Leach Cone-tainers (Stuewe and Sons, Inc., Tangent, OR) filled with sterilized river sand. Containers were placed in a greenhouse with ambient light with night/day temperatures of 30 ºC/26 ºC. All seed was hand-watered twice daily. After 33 days, 36 healthy seedlings were chosen and carefully removed from the container and sand was washed from their roots through repeated submersion in tap water combined with gentle agitation. Once all sand was removed, seedlings were placed in glass beakers filled with tap water, then placed in the liquid culture hydroponic system.

The liquid culture hydroponic system consisted of three individual hydroponic units installed in a controlled environment room (figure 6). Each individual hydroponic unit consisted of one 100-L PVC tank placed on a rolling metal frame with another 100-L PVC tank below for a total of 200-L of solution per unit. Seedlings were all grown in a 100-percent strength nutrient solution throughout the study. Nutrient solutions were circulated between tanks by enclosed pumps at a rate of 16 L/min. Aeration was supplied as solution from the upper tank fell back into the lower tank. A check valve located between the two tanks allowed for the isolation of tanks, which facilitated the replacement 100 L of nutrient solution weekly. Seedlings were grown with a 12:12 daily photoperiod and temperatures of 30 ºC/26 ºC.

The upper tank of each hydroponic unit was separated into three compartments with PVC walls. Each of the three divisions were further divided into four sections to isolate roots from each other while maintaining a uniform solution. While plants and roots were kept

Figure 6. Liquid culture hydroponic system. (Photo by Andrew Whittier, 2013)

Figure 7. Healthy teak seedling grown in full strength nutrient solution 6.0 pH. (Photo by Andrew Whittier, 2013)

separate, the nutrient solution was able to flow freely throughout the entire system. The upper tank was fitted with a PVC cover that held PVC discs over the three compartments. In each of these discs were openings that held foam plugs that were suspended directly over the hydroponic solution. Seedlings were placed in slits cut into the foam plugs with roots submerged into the nutrient solution.

Nutrient solutions were mixed with reagent grade chemicals and DI water and were based on a full-strength complete modified Hoagland's all-nitrate solution (Hoagland and Arnon 1950; table 1). Sulfuric acid was added to the solution following mixing in order to achieve an initial target pH. Using a pH meter (Model 5993-35, Cole-Parmer, Vernon Hills, IL) that displayed current levels on a pH monitor/controller, the three hydroponic units were set to three pH levels: 5.3, 5.8, and 6.3. Target pH was maintained through automated use of peristaltic pumps adding a calcium hydroxide (Ca(OH)2) base to the nutrient solution as needed. Only bases were added as the nutrient solution became gradually more acidic as seedlings took up nutrients. Weekly replacement of half of the solution in each unit was done to maintain a consistent nutrient solution throughout the study.

Height and basal diameter were measured weekly for 38 days, after which seedlings were removed and separated into leaf, stem, and root components. Fresh plant weights at the time of removal from hydroponics were recorded. Plant components were then dried in a forced-air oven at 60 ºC for 48 hours, then measured for dry weights. Height, basal diameter, wet plant weight, and dry plant weight means were analyzed using PROC ANOVA of the Statistical Analysis System software package (SAS 1988).

Results

After 38 days, none of the plants in the study had died. Growth was impressive regardless of pH levels (figure 7). Height of seedlings grown in pH 5.8 was significantly taller than those grown in pH 5.3, whereas basal diameter was unaffected by treatment (figure 8). There were no significant treatment differences in fresh or dry plant weights. This study indicates that teak grow well across a range of acidic pH values when adequate nutrients are supplied. Future studies looking at a more extreme pH range would help to more fully understand the upper and lower pH limits that hydroponically grown teak will tolerate.

Nutrient Solution pH Buffer Study

Materials and Methods

Following a 24-hour stratification in tap water, 220 teak seeds were sown 1 cm deep with micropyles down in germination flats filled with moist, sterilized river sand. Sown flats were placed in a greenhouse with ambient light and day/night temperatures of 30 ºC/26 ºC and were hand-watered twice daily. After 58 days, 20 germinants were randomly chosen and carefully removed from trays. Sand was washed from roots through repeated agitated dunking in tap water. Once the roots were thoroughly cleaned, 10 plants were installed into each of two hydroponic tanks. The hydroponic units utilized were the same as those described in the nutrient solution pH study. Each of the two tanks was filled with a 100-percent Hoagland nutrient solution and monitored for pH, as described in the nutrient solution pH study. The pH in both units was maintained at 6.0. In one tank, pH was maintained through the automated addition of a sodium hydroxide (NaOH) buffer through peristaltic pumps. In the other tank, the pH

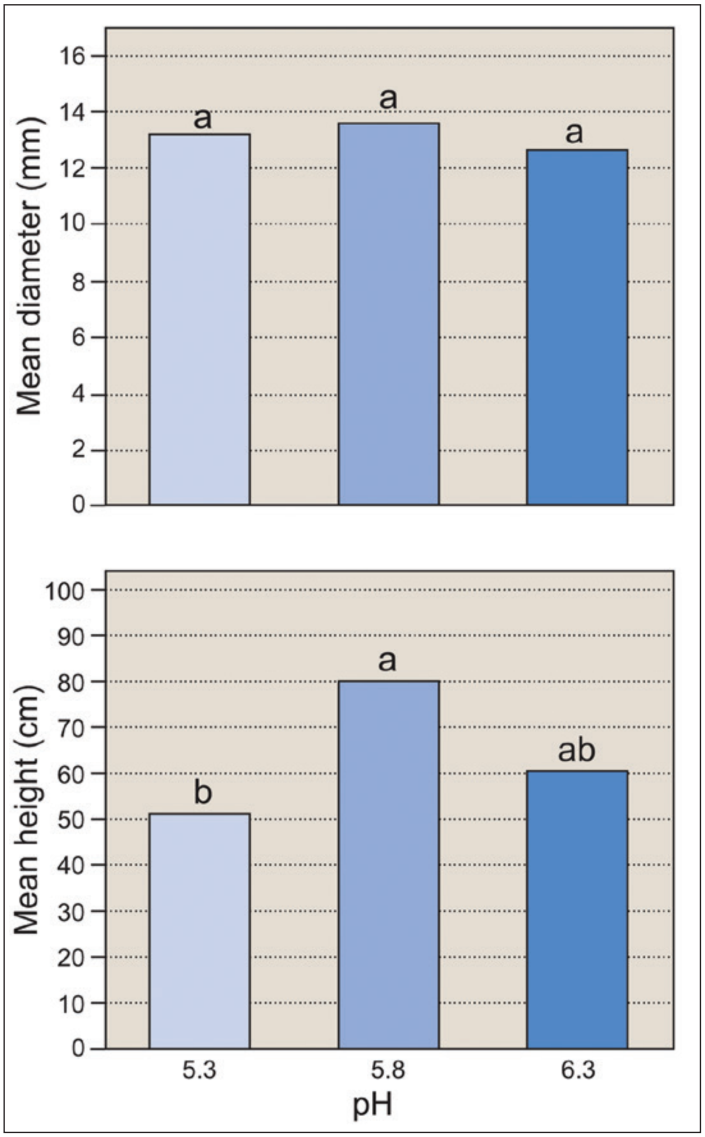

Figure 8. Teak seedling mean basal diameter and height after 5 weeks in three different pHs in liquid culture. Bars with the same letter are not significantly different at the P ≤ 0.05 level.

was maintained with a calcium hydroxide ($Ca(OH)_2$) buffer added through the same peristaltic pump system.

Seedling height and basal diameter were measured weekly for 8 weeks. Initial height of all 20 seedlings averaged 1.4 cm. Initial diameter was not recorded, as plants were too small and delicate to measure with calipers. At the completion of the study, plants were removed from the hydroponic solution and weighed for total fresh weight, as well as fresh weight of leaves, stems, and roots. Dry weight of plant parts was measured after 48 hours in a forced-air oven at 60 ºC for 48 hours. Height, basal diameter, wet plant weight, and dry plant weight means were analyzed using PROC ANOVA of the Statistical Analysis System software package (SAS 1988).

Results

After 56 days in the buffer study, one plant in each buffer treatment had died. Mean height and diameter between the two buffer treatments did not differ significantly at the $P \leq 0.05$ level (figure 9). Wet and dry plant weights between the two buffer treatments were also not statistically different.

The lack of significantly different rates of growth was unexpected, as teak has a reported high calcium demand. The lack of positive response to additional calcium may indicate that seedling calcium demands were met with the calcium provided in the full-strength Hoagland nutrient solution. The use of sodium hydroxide as a pH buffer is preferable to avoid issues with precipitates when using calcium hydroxide.

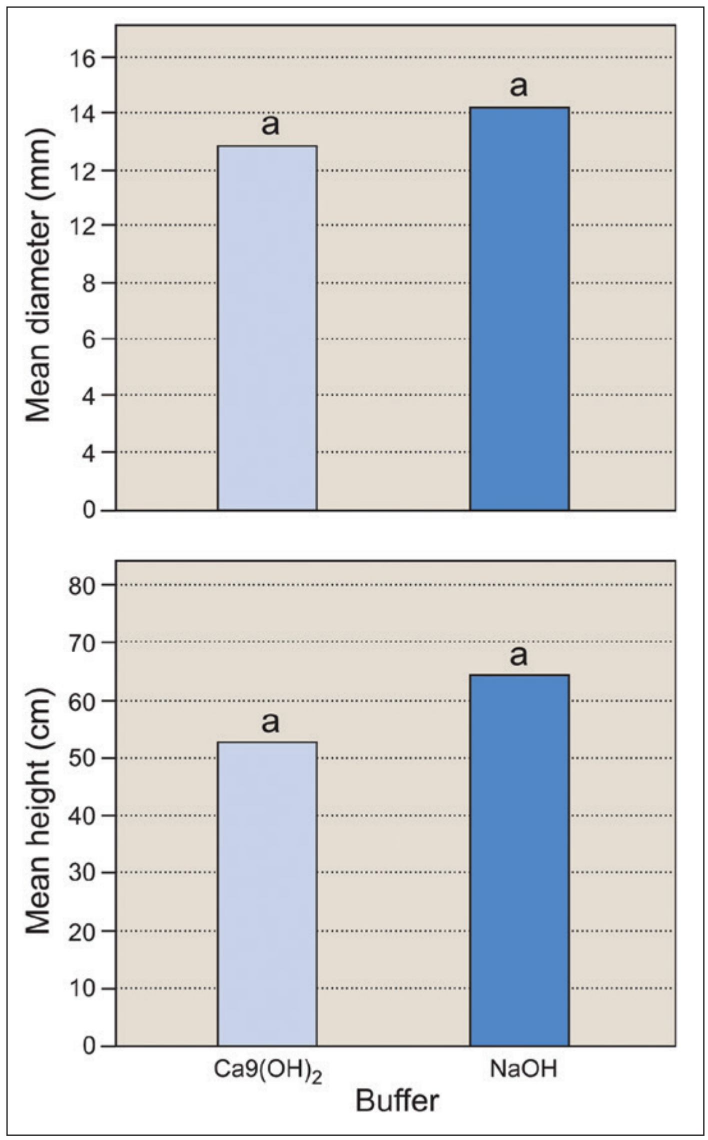

Figure 9. Teak seedling mean basal diameter and height at 8 weeks in two different buffers in liquid culture. Bars with the same letter are not significantly different at the P ≤ 0.05 level.

Recommendations

These preliminary studies helped to answer questions involving a suitable methodology for growing teak seedlings hydroponically in temperate greenhouses. Growth was adequate within greenhouses during the summer in a temperate climate. The use of a full-strength standard nutrient solution produced adequate growth in hydroponically grown teak seedlings.

Most hydroponic systems are designed to be slightly acidic (Bugbee 2004). Although the results in this study indicate that seedling growth was suitable at each of the tested pH levels, a target pH of 6.0 is recommended in future hydroponic studies due to the slightly improved height of seedlings in the 5.8 and 6.3 pH solutions.

To maintain a desired pH while plants take up nutrients from the hydroponic solution, buffers are commonly added to the nutrient solution (Bugbee 2004). We expected teak seedlings would respond well to a calcium hydroxide buffer because the species has a known high calcium demand (Weaver 1993), but there were no significant differences between buffer treatments. In future liquid culture hydroponic studies, we recommend sodium hydroxide as a buffer because of its ease of use with peristaltic pumps.

In summary, this research illustrated that teak seedlings would respond well to both sand and liquid culture hydroponic greenhouse setups. Based on these findings, we recommend that future hydroponic teak seedling studies use a full-strength standard Hoagland nutrient solution at a pH of 6.0 with a sodium hydroxide buffer.

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