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Reproductive Maturity Onset and Tree Size in a *Garcinia kola* (Heckel) Coastal Humid Tropical Climate Plantation

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Abstract

Little is known of the life history of *Garcinia kola*; the objective of this study, therefore, was to assess the fruiting age and tree size of the species in a coastal humid tropical climate plantation condition. A total 103 trees were used in the study viz; 80 ten-year-old trees at reproductive maturity onset and 13 thirty-year-old trees with several cycles of reproduction that constitute two independent variables. Data collected were age of onset of flowering and size at reproductive maturity onset. Relative size at reproductive maturity onset (RSOM) was estimated as size at reproductive maturity onset (SOM) divided by asymptotic maximal size (AMS). Data analysis was conducted using pairwise t-test and principal component analysis (PCA). Reproductive maturity onset (flowering) was recorded in the ten-year-old stand eight (8) years after planting. Mean size at reproductive maturity onset (SOM) was height 5.32±1.7 m, dbh 0.11±0.03 m, total number of branches was 29.6±7.3, crown depth 5.24±1.05 m, crown diameter was 4.78±0.7 m, branch diameter 0.098±0.01 m, leaf length 0.13±0.02 m, leaf breadth 0.37±0.01 m, twig length 0.35±0.11 m and leaf per twig 6±0.84 and asymptotic maximal size (AMS) was height 19.85±0.76 m, dbh 0.95±0.09 m, total number of branches 62±5, crown depth 18.83±0.7 m, crown diameter 12.5±1.64 m, branch diameter 0.5±1.6 m, leaf length 0.16±0.023 m, leaf breadth 0.45±0.12 m, twig length 0.37±0.11 m and leaf per twig 19±7.5. Pairwise t-test analysis showed there was significant differences between SOM and AMS in all growth factors except leaf length, leaf breadth, and twig length. Highest relative size at reproductive maturity onset (RSOM) was recorded in leaf length 0.82, twig length 0.82, and leaf breadth 0.80, while, the lowest was branch diameter 0.11. Four components out of the total of eleven were extracted to explain the relationship in RSOM: Principal component one (PC1) explained 37.23%; PC2 26.4%, PC3 22.73%, and PC4 13.64%.

Key Words: maturity, age, relative-size, reproductive-onset, asymptotic

Introduction

Plants as well as animals vary in their pattern of development, duration of growth, maturation time, number of offspring, size of offspring at birth, and duration of lifetime; "age, size, or stage-specific patterns of development, growth, maturation, reproduction, survival, and lifespan define an organism's life cycle, or life history" (Fabian and Flatt 2012). Life-history theory studies the schedule, duration, and relative allocation of energy to key events in an organism's lifetime. This is underpinned by the assumption that natural selection acts upon traits such as survival, growth, and reproduction to produce the largest possible number of surviving offspring (Stearns 1977, 1992; Roff

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2002). The underlying premise of life history theory can be summarized briefly as follows: resources are finite; hence, organisms must make trade-offs in terms of the amount of energy they devote to different traits. For example, energy used for current reproduction is likely to be paid for in terms of energy available for future reproduction or growth (Stearns 1992).

The life history of many trees particularly is often associated with first a prolonged sterile period (i.e. seeds, seedlings and saplings), a second stage of initial flowering and a final stage of prolonged fertile stage (adults). For many tropical tree species life history traits and or transitions from the sterile, juvenile stage to the fertile, adult stage is virtually unstudied despite its obvious importance for individual fitness, population growth rates and species coexistence and community diversity. More likely, early reproduction will incur costs including lower growth, seed production and/or survival in the future leading to a trade-off between early reproduction and lifetime seed production (Wesselingh et al. 1997; Augspurger and Bartlett 2003). This trade-off could contribute to species coexistence in several ways. Greater reproductive capacity, which might be achieved in part through early reproduction, may allow small-stature, shade-tolerant tree species to coexist with larger and inherently superior competitors for light (Kohyama 1992). Life-history trade-offs do not act in isolation and are not mutually exclusive. As a matter of fact the diversity of life-history strategies replete in nature is largely due to synergistic interactions among competing selective demands acting on different life-history traits (Hairston 1983; Stearns 1992; Roff 2002; Groover 2017). Furthermore, the relative costs and benefits of investing energy on any particular traits is not static and may vary through time, ontogeny, hierarchical levels of modular organization, and among different environments (Stearns 1992; Roff 2002). Thus, the life-history of any particular tree is a product of complex interactions among numerous selective forces varying over both space and time.

Little is known particularly of the life history of *G. kola* particularly as it relates to the fruiting age and vegetative traits of a reproductively mature tree of seed origin which often discourages the cultivation of the important fruit tree. The study therefore aimed to document the fruiting age or age of reproductive maturity onset and the accompanying vegetative traits (i.e. tree size) of *G. kola* trees established in a coastal humid tropical climate plantation. This is against the backdrop of a growing need for the plantation establishment of the species vis-à-vis the multipurpose value of the tree.

Materials and Methods

Plantation description

The study was conducted in an artificial mono-plantation of *Garcinia kola* propagated from seed at the Swamp Forest Research Station, of the Forestry Research Institute of Nigeria (FRIN), Onne Rivers state Nigeria (Fig. 1). The plantation consists of about 13 trees 23-year-old and 80 trees 13-year-old at 5 m by 5 m spacing. Flowering and fruiting events occur in the plantation about 3-4 times in a year and overlap i.e. flowers and fruits are present in the plantation almost all year round. Flowering and fruiting intensity per event was however variable but peaks in August-October. The plantation is located on Latitude 4°42'-10°32'N and Longitude 7°10'-32°46'E, with 2,400 mm mean annual rainfall, relative humidity 78% in February (dry season) and 89% in July (rainy season), mean annual temperatures of 27°C in February and 25°C in July. Soils are ultisols derived of coastal sediments, highly acidic (pH 4.4), with low fertility, and classified as siliceous, iso-hyperthermic, typic paleudult, usually deep, chemically poor, well drained with good physical properties. The vegetation is a humid rainforest in a mangrove transition forest zone (Okonkwo and Omokhua 2022).

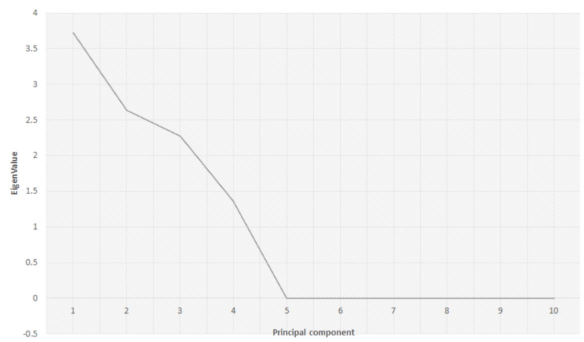

Fig. 1. Principal components and eigen values of relative size at reproductive maturity onset of *Garcinia kola*.

Species description

Garcinia kola commonly known as bitter kola is an evergreen tropical rainforest species found in West and Central Africa within which Nigeria and Cameroon are considered the areas of highest endemism (Maňourová et al. 2019). *G. kola* is mostly found in moist or coastal forests, lowland rainforests, and derived savannah in West Africa, a distribution pattern largely influenced by rainfall and temperature (Agwu et al. 2020). In the wild *G. kola* trees can grow up to 12 m high and trees as high as 27 m has been reported (Keay et al. 1964). The bole is mostly straight with brownish smooth bark that produces sticky-yellow water proof latex when wounded which is a trademark of the Clusiaceae family and crown is usually dense, especially in female trees, with slightly drooping branches (Keay et al. 1964; Maňourová et al. 2019). Mature *G. kola* leaves are dark green in colour while younger leaves are light greenish and can be up to 6.35-13.97 cm long and 2.5-6.35 cm wide, elongated elliptic to broadly elliptic, acute or shortly acuminate, and cuneate. The leaves are also leathery with very distinct resinous canals; the inflorescence is a terminal umbel with greenish-white flowers on short stalks about 7.62 mm long. Flowers are about 19.05 mm wide with stamens in four broad bundles that alternate with the four fleshy lobes of the disc; ovary is finely hairy, stigmas are 4-lobed and flattened; Male flowers usually are smaller but with more prominent stamens *G. kola* flowers between December and January and fruits between July and October; fruits are reddish yellow and about 63.5 mm wide with 2-4 brownish seeds; the wood is close grained, hard, yellow in colour but darkens to brown at the centre (Keay et al. 1964; Maňourová et al. 2019). *G. kola* is valued as a multipurpose tree used as timber and seed, twig, fruit, bark and leaves valued as potent antibiotics for the treatment of common ailments such as cough, pneumonia, tooth ache, etc. There is therefore a growing interest in the plantation establishment of the species in Nigeria due to dwindling wild supplies of the products (Okonkwo and Omokhua 2022).

Experimental design and data collection

A total of eighty (80) thirteen-year-old trees were used in the study of reproductive maturity onset; while, twenty (20) trees i.e. ten (10) 13-years-old trees and ten (10) twenty-three-year-old tree with several cycles of reproduction that constitute two independent variables were employed in the study of relative size at reproductive maturity onset. Data collected were age of onset of flowering/fruiting, size at reproductive maturity onset viz; tree height, branch diameter, crown diameter, crown depth, and diameter at breast height taken with a measuring tape; leaf length, leaf breadth, length, twig length, taken with measuring ruler; number of branches, and number of leaves per twig were counted; twig was collected from the lowest hanging branches. Data analysis was conducted using pairwise t-test and principal component analysis (PCA). Relative size at reproductive maturity onset (RSOM) was calculated for the plantation according to Thomas (1996):

$$\text{RSOM} = \frac{\text{Size at reproductive onset (SOM)}}{\text{Asymptotic maximal size (AMS)}} \tag{1}$$

Where;

SOM = tree size (height, diameter, crown diameter, etc.) at reproductive maturity onset; and

AMS = tree size (height, diameter, crown diameter, etc). of the largest older trees.

Asymptotic size was calculated using the largest trees in the plantation as proposed by Stamps and Andrews (1992) and the following three conditions of the method were fulfilled: (1) there were trees in the population that were near their final asymptotic size (slowed size increase), (2) plantation has largest individual trees that are close to the average asymptotic size. (3) coefficient of variation among asymptotic size was relatively low.

Results and Discussion

Age at reproductive maturity onset

Reproductive maturity onset (evidenced by flowering and fruit production) was recorded in both the 13-year-old (2010-2023) and twenty-three-year-old (2000-2023) eight (8) years after planting. This age of reproductive maturity onset in the plantation is consistent with the range 7-15 years reported by Maňourová et al. (2019) in a review of silvicultural management and cultivation of *G. kola*. However, the age of reproductive maturity in the plantation contrasts with the 10-15 years reported by Adebisi (2004) while investigating the production and consumption of *G. kola* in J4 Ogun state South-west Nigeria. Thus, corroborating the report of Stearns (1992) and Roff (2002) that reproductive maturity onset in any particular species may vary with environment. Moreover, Agwu et al. (2020) studying the impact of climate on ecology and suitable habitat of *Garcinia kola* in Nigeria, confirmed that the distribution of the species in the country is largely controlled by precipitation and temperature. Furthermore, since *G. kola* is evergreen it is clear the species thrives better in areas of high rainfall and lower relative temperature and is the reason Isawunmi (1993) reported the species occurs predominantly in coastal climates and lowland rainforests. Hence, we propose that *G. kola* achieves reproductive maturity onset earlier and faster in the humid coastal rainforest than anywhere else. We have as a result liaised with our sister research station in the lowland rainforest zone to conduct similar studies to test the hypothesis.

Eight-eight percent (88%) i.e. seventy (70) trees of the total eighty 13-year-old trees did not produce flower or fruit in the 8th year but in the 10th and 11th and so on. This gives an indication that reproductive onset in the species could vary with individual tree's unique genetic time clock and possibly physiological readiness or preparedness to come to flower as dictated by the availability of sufficient resources to kick-start reproduction. This conclusion is drawn from the fact that the population under study is a mono plantation at 5 m by 5 m spacing and as such above ground and below ground competition is minimal. However, there remains to determine if aspect, elevation, slope and light intensity (Temesgen et al. 2014; Malizia et al. 2020) influenced the onset of reproduction since *G. kola* is naturally an understory species according to Keay et al. (1964). Moreover, since the population of *G. kola* is subdioecious with documented evidence of sexual dimorphism (Okonkwo and Omokhua 2022) there would be the need to ascertain the role of tree sex in reproductive maturity onset i.e. there is need to determine if the population shows sexual dimorphism in reproductive maturity onset; in which case either of the three sexes male, female, or cosexual tree could achieve reproductive maturity onset earlier.

The far reaching implications of the tree-to-tree disparity in reproductive maturity onset in the plantation found in this study is that it can influence the gene pool of the next generation of the trees; the first trees to reproduce automatically are first to colonize and establish themselves (Wright et al. 2005) and are therefore most likely to be the dominant genotypes in the long run in the plantation except there is an intensive management of establishments in the plantation. Furthermore, the plantation of the study serves both the purpose of research and seed collection; therefore it is obvious that the seeds of the of first trees to come to reproduction are normally those propagated and used in current plantation establishments and even carried further away to many other provenances by seed collectors. This shows therefore that in the wild reproductive maturity onset is a key contributor to within population genetic diversity. Reproductive maturity onset would increase genetic diversity or maintain it if older trees are still reproductively active; however, when there are a large number of old trees

Table 1. Size at reproductive maturity onset (SOM), asymptotic maximal size (AMS), coefficient of variation and relative size at reproductive maturity onset (RSOM)

Traits	SOM	AMS	CV (%)	RSOM
Height (m)	5.32±1.7	19.83±0.76	3.8	0.268
Dbh (m)	0.11±0.03	0.95±0.09	9.47	0.115
Branch number (count)	29.6±7.3	62±5	8.1	0.477
Crown depth (m)	5.24±1.05	18.83±0.7	3.7	0.280
Crown diameter (m)	4.78±0.7	12.50±1.64	13.12	0.380
Branch diameter (m)	0.098±0.01	0.5±0.02	4.0	0.196
Leaf length (m)	0.13±0.02	0.16±0.023	14.4	0.812
Leaf breadth (m)	0.37±0.01	0.45±0.12	12.2	0.822
Twig length (m)	0.35±0.11	0.37±0.11	29.7	0.945
Leaf per twig (count)	6±0.84	19±7.5	39.47	0.316

that are reproductively inconsistent, or outrightly removed due to anthropogenic activities or even disease, early reproductive onset can provide an avenue to replenish the population albeit with a trade-off in the form of some reduction in genetic diversity of the next generation.

Size at reproductive maturity onset (SOM) vs. asymptotic maximal size (AMS)

Mean height at reproductive maturity onset (SOM) was 5.32±1.7 m and asymptotic maximal size (AMS) 19.85±0.76 m; mean dbh was SOM 0.11±0.03 m and AMS 0.95±0.09 m; mean total number of branches was SOM 29.6±7.3 and AMS 62±5 m; mean crown depth was SOM 5.24±1.05 m and AMS 18.83±0.7 m; mean crown diameter was SOM 4.78±0.7 m and AMS 12.5±1.64 m; mean branch diameter was SOM 0.098±0.01 m and AMS 0.5±1.6 m; mean leaf length was SOM 0.13±0.02 m and AMS 0.16±0.023 m; mean leaf breadth was SOM 0.37±0.01 m and AMS 0.4±0.12 m; mean twig length was 0.35±0.11 m and AMS 0.37±0.11 m; mean number of leaf per twig was SOM 6±0.84 and AMS 19±7.5 (Table 1). Pairwise t-test analysis showed there was significant differences between SOM and AMS in height, diameter at breast height (dbh), crown depth, crown diameter, number of branches, branch diameter, and number of leaf per twig; however there was no significant differences in leaf length, leaf breadth, and twig length between the two sizes. Hence, implying that at reproductive maturity onset leaf and twig size are almost the same size as those at maximal size (Table 2). Therefore, leaf and twig size can cannot be used to identify reproductively mature *G. kola* trees in the plantation. Comparative study of leaf size variations along different stages of the tree development and growth of the species will be required to fully settle this hypothesis. Aside from the leaf size, the AMS was three times larger than the SOM in the rest of the growth traits which is in agreement with Harper and White (1974) who reported that tree species increase substantially in size after they achieve reproductive onset. The mean asymptotic maximal height of 19.83±0.76 m reported in this study is by far above the highest average of 16.5 m reported by Maňourová et al. (2019) and 12 m by Keay et al. (1964); however reported that *G. kola* trees sometimes grow to a rare height of 27 m.The age or size threshold at which a tree species begins to reproduce goes a long way to determine its population growth rate, seed availability, and persistence (Thomas 1996) and even its desirability for cultivation. Shorter juvenile period to reproductive maturity onset is a quality highly desirable in fruit tree species particularly species selected for domestication and cultivation such as *G. kola*.

Table 2. Pairwise t-test comparison of size at reproductive maturity onset (SOM) and asymptotic maximal size (AMS)

SOM×AMS	p-value	Mean
Height	0.01**	10.9
Dbh	0.03**	0.38
Branch number	0.01**	50
Crown depth	0.01**	10.1
Crown diameter	0.01**	8.59
Branch diameter	0.00**	84.4
Leaf length	0.74*	0.48
Leaf breadth	0.29*	0.58
Twig length	0.73*	1.80
Leaf per twig	0.00**	13.2

Dbh, diameter at breast height.

*Not significant ($p>0.05$), **significant ($p<0.05$).

Relative size at reproductive maturity onset (RSOM)

Highest relative size at reproductive maturity onset (RSOM) was recorded in leaf length 0.82, twig length 0.82, and leaf breadth 0.80; this is followed by total number of branches 0.47 and crown diameter 0.38; and number of leaf per twig 0.28, crown depth 0.28, tree height 0.27, diameter at breast height (dbh) 0.27; while the lowest was branch diameter 0.11 (Table 1). In literature estimates of RSOM for growth parameters other than dbh and height are not common. Comparing RSOM in about thirty-seven Malaysian rainforest species Thomas (1996) used the relationship between tree diameter at breast height (dbh) and total height to estimate mean RSOM for Garcinia bancana as 0.66 at 15.87 m and 30.5 m mean asymptotic maximal dbh and height respectively; *G. malaccensis* as 0.27 at 4.0 m and 15.7 m mean asymptotic dbh and height respectively; *G. nervosa* as 0.60 at 17.22 m and 34 m asymptotic maximal dbh and height respectively; and *G. scortechinii* as 0.3 at 2.34 m and 13.7 m mean asymptotic maximal dbh and height respectively. RSOM of 0.27 reported by Thomas

(1996) for *G. malaccensis* at 4.0 m and 15.7 m mean asymptotic dbh and height respectively is exactly the same with that of *G. kola* of 0.27 at 0.95 m and 19.98 m mean asymptotic maximal dbh and height respectively.

Since RSOM is interpreted as the percentage size at reproductive maturity onset (SOM) relative to the asymptotic maximal size (AMS) (Stamps and Andrews 1992; Wright et al. 2005). It means that the relative size threshold of reproductive maturity onset in *G. kola* is 27% of the asymptotic maximal size of 0.95 m dbh and 19.98 m height respectively. Cultivation of the species therefore must focus on sites that are most suitable to the earlier achievement of the size for early fruiting vis-à-vis the high economic and medicinal value of the tree. Attention must also be given to silvicultural and nursery practices that enhance height and diameter growth, hence the need for studies that can aid to provide the information. Charnov (1990) further opined that RSOM as a dimensionless constant can be used to describe life history variations as well as species-specific growth and mortality rates.

Association between relative size at reproductive maturity onset (RSOM) of different traits

Using Kaiser rule of eigenvalue greater than 1 (Johnson and Wichern 1992) four principal components out of the total of eleven were extracted to explain the variation in RSOM of the different traits (Table 3); principal component one (PC1) explained 37.23% of the variation; PC2 explained 26.4%; PC3 explained 22.73%; and PC4 explained 13.64% (Table 4). RSOM communality factor was 1 for each of the growth traits (Table 4); which means a high level of relationship between the RSOM of the traits.

Relative size at reproductive maturity onset (RSOM) of diameter at breast height (dbh), number of branches, branch diameter, crown diameter and twig length had positive high loadings on PC 1; which implies significant positive correlation between these traits; hence, RSOM of a

Table 4. Principal components and percentage explained variation

PC	% Relationship explained	Cum % relationship explained
1	37.23%	37.23%
2	26.40%	63.62%
3	22.73%	86.36%
4	13.64%	100.00%
5	0.00%	100.00%
6	0.00%	100.00%
7	0.00%	100.00%
8	0.00%	100.00%
9	0.00%	100.00%
10	0.00%	100.00%

PC, principal component; %, percent variation explained by component; cum %, cumulative percent of variation explained by components.

Table 3. Principal components and communality factor of relative size at reproductive maturity onset (RSOM)

Factor matrix (rotated varimax)						
Growth traits	PC1	PC2	PC3	PC4	Communality	Specific
Height	0.125	-0.954**	0.272**	0.038	1	0.00
Dbh	0.317**	0.835**	0.091	0.441**	1	0.00
No. of branches	0.281**	-0.432**	0.843**	0.150	1	0.00
Crown height	0.126	-0.418**	-0.216**	-0.874**	1	0.00
Crown diameter	0.959**	-0.252**	0.057	-0.118	1	0.00
Branch diameter	0.310**	-0.604**	-0.734**	0.018	1	0.00
Leaf length	-0.000	0.057	-0.997**	0.058	1	0.00
Leaf breadth	-0.625**	-0.121	-0.520**	0.570**	1	0.00
Twig length	0.343**	0.076	0.128	-0.927**	1	0.00
Leaf per twig	-0.934**	-0.196	0.060	0.293**	1	0.00

PC, principal component.

**Size loading ≥ 0.2 = significant (size loading < 0.2 = not significant); communality factor ≥ 0.5 = significant; specific factor < 0.5 = not significant.

trait such as dbh (which is easily measurable) can be used as a representative for RSOM of number of branches, branch diameter, crown diameter and twig length. Leaf breadth and number of leaf-per-twig however showed a negative high loading on PC 1; this implies that RSOM of leaf breadth and number of leaf per twig are associated and can represent each other; Diameter at breast height (dbh) RSOM showed a positive high loading on PC2; whereas mean tree total height, number of branches, crown height, crown diameter, and branch diameter showed a negative high loading on the component; hence, tree total height RSOM was inversely correlated with dbh RSOM and tree total height RSOM can represent that of those traits that are correlated with it; PC 3 showed a positive high loading of tree total height and number of branches RSOM but a negative high loading of crown height, branch diameter, leaf length and leaf breadth RSOM which implies that tree total height RSOM can represent RSOM of number of branches while crown height, branch diameter, leaf length and breadth can represent each other; PC 4 showed dbh RSOM with a positive high loading with leaf breadth and mean number of leaves per twig but a negative high loading of crown height and twig length. Since the RSOM of dbh and total height are correlated with almost all the other growth traits the study concludes that dbh and total height RSOM can be taken as representative for the RSOM of the tree growth traits. This is in agreement with a general consensus that dbh and tree height are representative traits in tree growth assessment (King 1990; Huang et al. 2002). However, it must be stated that dbh and height traits of trees vary from site to site as they are controlled by prevalent ecological factors such as edaphic and climatic factors (Canham et al. 2006); they are also controlled by the density of planting and particular tree position relatives to the rest of the population (Temesgen and von Gadow 2004; Temesgen et al. 2007); hence dbh and height traits of an open and plantation grown plant or population may vary. This implies therefore that RSOM may vary according to the provenance of *G. kola* tree population under study (Huang et al. 2002).

Conclusion

The age of reproductive maturity onset (i.e. fruiting age) of *G. kola* trees of seed origin established in a humid tropical rainforest climate plantation was eight (8) years. The percentage of trees that flowered or fruited at this age was 22% which has consequences for the fruit/seed yield of the plantation at the reproductive maturity onset; as well as implications for the genetic diversity of seed collected from the plantation. At the reproductive maturity age of eight-years *G. kola* trees were three times smaller than the size of twenty-three-year old trees in the humid tropical rainforest plantation; particularly the dbh and height of trees at reproductive maturity onset were 27% the size of twenty-three-year old trees. This all shows that *G. kola* trees in plantation conditions of the humid coastal tropical climate of southern Nigeria fruits at relatively young age and tree size. This information provides a background of idea of what to expect in terms of reproductive age and tree size in a plantation of *G. kola* in the climatic zone. Moreover, the potential farmer or firm willing to establish commercial plantation of the species in the area can have an idea of when to expect financial returns and at what rate.

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