Survival, Growth, Yield, Stem Form and Wood Basic Density of *Pinus oocarpa* Provenances at Buhindi, Mwanza, Tanzania

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(Received 13th November 1997)

Summary

The performance of 16 *Pinus oocarpa* (including 5 now reclassified as *Pinus patula* spp. *tecunumanii*) provenances at Buhindi Mwanza, Tanzania: is evaluated in terms of survival, height growth, breast height diameter, basal area per ha, wood basic density and stem form. The final assessment was carried out at the age of 22 years.

The main results of the study were:

– Before angular transformation, survival varied from 77% (Rafael, Nicaragua) to 56% (Conacaste, Guatemala). However no significant difference ($P > 0.05$) in survival was detected after such transformation.

– Height growth showed significant differences ($P < 0.05$) at all ages. At 22 years the outstanding provenances were Siguatepeque (Honduras), Rafael (Nicaragua), and Zamorano (Honduras). Least height growth was shown by Bonete (Nicaragua) provenance.

– Significant differences ($P < 0.05$) were detected in breast height diameter. Outstanding provenances were Yucul, Camelias (Nicaragua) and Mt. Pine Ridge-K49 (Belize). Least performers were Zamorano (Honduras) and Lagulnilla (Guatemala) provenances.

– Significant differences ($P < 0.05$) were detected in basal area per ha development. The Bucaral (Guatemala) provenance was outstanding while least basal area development was recorded in the Conacaste, Lagunilla (Guatemala) and Siguatepeque (Honduras) provenances.

– The Bucaral (Guatemala) provenance was significantly superior ($P < 0.05$) in wood basic density. Least wood basic density values were recorded from Camelias, Yucul, Rafael, Junquillo (Nicaragua), Angeles (Honduras) and the Lagumilla (Guatemala) provenances.

– No significant differences ($P > 0.05$) in stem form were observed.

It is suggested that the 5 *Pinus patula* SCHIEDE and DEPPE ssp. *tecunumanii* (EQUILUZ and PERRY) provenances are likely candidates for species diversification in the Lake Victoria zone where the main plantation species is *Pinus caribaea.* However, noting that more than half of the natural distribution of *P. oocarpa* occurs outside central America, more provenances need to be tested to cover that extended range. Similarly, the sparse sampling of *P. patula* ssp. *tecunumanii* also needs additional representation.

Restricting the results of this study to *Pinus oocarpa,* provenance ranking in diminishing order of performance gives: Bucaral (Guatemala), Zapotillo, Zamorano (Honduras), Chuacus (Guatemala), Siguatepeque (Honduras), Bonete, Junquillo (Nicaragua), Conacaste (Guatemala), Angeles (Honduras) and San Jose (Guatemala); and Lagunilla (Guatemala).

In descending order of performance, suitable *Pinus patula* ssp. *tecunumanii* provenances are Mt. Pine Ridge (K49), Mt. Pine Ridge (K29), Rafael, Yucul and Camelias (Nicaragua).

Key words: Pinus oocarpa, P. patula ssp. *tecunumanii,* provenances, natural range, alternative species.

FDC: 181.64/.65; 232.12; 561; 812.31; 174.7 *Pinus oocarpa;* 174.7 *Pinus patula;* (678).

Introduction

Increasing demand for industrial wood, construction poles, fuelwood, as well as to reduce exploitation pressure on indigenous forests are among other reasons the basis of the plantation forestry programme in Tanzania (NSHUBEMUKI *et al.,* 1996b).

The total area covered is some 80000 hectares. The main species planted are *Pinus patula, P. caribaea, P. elliottii, Cupressus lusitanica, Tectona grandis* and several *Eucalyptus* species.

Pinus caribaea the extensively planted pine is second most planted species at Buhindi (3209 ha), Rubya (1816 ha) and Rubare (200 ha); and covers some 1654 ha in the Rondo plantations (NSHUBEMUKI *et al.,* 1996a). In an effort to overcome the problem of monoculture planting, a *Pinus oocarpa* provenance trial was initiated in 1973 at Buhindi as it was then believed that this species is a possible substitute for *Pinus caribaea.*

This paper gives the perfomance of 16 *P. oocarpa* provenances that were tried. Analysis is focused on survival, height, and diameter growth, yield, stem form and wood basic density. Attention is also briefly directed to recent changes in the taxonomy of *Pinus oocarpa.*

Materials and Methods

The site

The experiment was established at the Buhindi Forest Plantations (32° 20'E; 2° 30'S). The area receives about 1340 mm of rain a year. Altitude is about 1200 masl. Geologically Buhindi is dominated by granite with pockets of quaternary sediments (SAGGERSON, 1962). The soils are light yellowish brown to reddish yellow, gritty, sandy clay loams. Base saturation varies from 5% to 60% with total exchangeable bases from 1 cmol to 5 cmol (+) per kg (SCOTT, 1962). Selected soil properties are presented in *table 1.* The pH in the pedon sampled to 50 cm depth ranged from 4.66 to 4.93, electrical conductivity from 1.45 to 0.023 dS m^{-1}, total nitrogen from 0.14% to 0.07%, and available phosphorus from 3.21 to 1.85 μg^{-1} (*Table 1*). The original vegetation consisted of *Acacia spp., Anisophyllea boehmii, Balanites aegyptiaca, Brachystegia boehmii, Burkea africana, Combretum* spp., *Grewia bicolor, Pericopsis angolensis, Pterocarpus angolensis, Terminalia sericea,* and *Vitex mombassae.*

Sources of seed and nursery techniques

Sources of *P. oocarpa* seed sown in April 1972 at Buhindi are presented in *table 2.* Seedlings were raised using standard cultural techniques (Forest Division, 1982).

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Table 1. – Means of selected soil properties of *Pinus oocarpa* and *Pinus patula* spp. *tecunumanii* provenances experimental site at Buhindi, Mwanza, Tanzania.

Soil depth	E.C.	pH(H_2O)	Organic Carbon	Total N	Total P	Available P
cm	dS m^{-1}		%	%	µg g^{-1}	µg g^{-1}
Litter	1.449[2]	4.93	3.21	0.14	278.5	20.70
	(0.028)	(0.08)	(0.41)	(0.02)	(71.9)	(0.41)
0-10	0.046	4.68	2.28	0.07	217.0	9.95
	(0.007)	(0.09)	(0.13)	(0.01)	(31.4)	(1.86)
10-20	0.032	4.66	1.85	0.10	183.0	6.57
	(0.005)	(0.10)	(0.05)	(0.01)	(30.4)	(1.35)
20-30	0.027	4.74	1.86	0.08	183.0	6.72
	(0.005)	(0.14)	(0.18)	(0.01)	(40.7)	(0.73)
30-40	0.023	4.73	2.08	0.07	165.5	6.84
	(0.002)	(0.05)	(0.10)	(0.01)	(31.5)	(1.15)
40-50	(0.024)	4.86	1.98	0.07	247.5	6.25
	(0.003)	(0.05)	(0.17)	(0.01)	(30.7)	(1.24)

[2]) Number of observations (n) per depth increment were 5; mean with standard error in parentheses.

Table 2. – Seed sources of *Pinus oocarpa* and *Pinus patula* spp. *tecunumanii* (indicated by asterisks) provenances planted at Buhindi, Mwanza, Tanzania.

Provenance No	Locality (Acronym)	Country	Latitude ° ' N	Longitude ° W	Altitude masl	Mean annual rainfall (mm)
*K2	Camelias (CAM)	Nicaragua	13 46	86 18	1000	1500
*K42	Yucul (YUC)	Nicaragua	12 55	85 47	900	1400
*K44	Rafael (RAF)	Nicaragua	13 12	86 06	1100	1500
*K49	Mt. Pine Ridge (MPO1)	Belize	17 00	88 55	953	2064
*K29	Mt. Pine Ridge (MPO2)	Belize	n.a.[x]	n.a.	n.a.	n.a.
K6	Zapotillo (ZAP)	Honduras	14 37	87 02	1000	1200
K11	Conacaste (CON)	Guatemala	15 10	89 21	650	1900
K31	Junquillo (JUN)	Nicaragua	13 42	86 35	1000	900
K32	Bonete (BON)	Nicaragua	12 50	86 18	1000	950
K34	Bucaral (BUC)	Guatemala	15 01	90 09	1100	800
K35	Angeles (ANG)	Honduras	14 07	87 04	1300	950
K36	Zamorano (ZAM)	Honduras	13 51	86 59	1000	1100
K43	Lagunilla (LAG)	Guatemala	14 42	89 57	1300	950
K45	Siguatepeque (SIG)	Honduras	14 42	87 47	1100	1250
K46	Chuacus (CHU)	Guatemala	15 02	90 16	1300	800
K47	San Jose (JOS)	Guatemala	14 28	89 28	1000	1000

[x]) n.a. = not available

Experimental design and field procedures

A randomised complete block design was used. The experiment consists of 16 provenances (*Table 2*) replicated five times. For each plot, provenance within each block, 7 x 7 trees were planted at a spacing of 2.5 m x 2.5 m. These 49 trees constituted a sample plot. The distance between plots was 3 m while blocks were separated by 4 m.

The site was prepared by complete clearing of all vegetation, destumping followed by staking and pitting. Pit size was 30 cm x 30 cm. Planting was done during the last week of April 1973. Spot weeding was carried out twice a year in the first two years and once a year until canopy closure when weeding was stopped at age 5 years. All trees were pruned to half height in 1979.

Data collection

Previous assessments

Data on previous assessments of tree survival, breast height diameter (DBH) and height were obtained from the Lushoto Silviculture Research Centre of the Tanzania Forestry Research Institute. Assessments were carried out 1, 4 and 13 years after establishment.

Latest assessment

The latest assessment was carried out in March 1995 at the age of 22 years. The parameters assessed were DBH, height, survival, stem form and wood basic density. For each provenance DBH of all surviving trees was measured to the nearest 0.1 cm using a diameter tape. The DBH tally also gave tree survival. Height assessment involved measuring three tallest trees giving the dominant height. This was later followed by measuring two sets of two trees representing medium and low height classes. Mean height was obtained by summation of the three height classes and dividing by 7. Stem quality was categorized as follows,

Score	*Quality*
1	Straight
2	Presence of a slight bend
3	Crooked

For the determination of wood basic density, four defect – free trees with straight bole and representative of the diameter ranges of each provenance were sampled. Wood cores were then taken from the selected trees using an increment borer. Wood cores were immediately dried to prevent fungal growth, and later subjected to basic density determination by the procedure described earlier (NSHUBEMUKI *et al.,* 1996b).

Soil sampling and analysis for site characterization

Soil sampling was done in February 1994. Five soil pits were located at random and dug to 50 cm depth. Within each pit, soil samples were taken from the following depth: LFH-layer 0 to 10 cm, 10 to 20 cm, 20 to 30 cm, 30 to 40 cm and 40 to 50 cm. Soil samples taken from the same depth within the same block were combined and a subsample taken for laboratory analysis. In the laboratory, soil samples were air dried and sieved through a 2-mesh sieve. Mineral soil particle size distribution was then determined by the hydrometer method. Soil pH and electrical conductivity were determined at a water:soil ratio of 2:1 by means of hydrogen electrode pH and electrical conductivity meters, respectively. A subsample of 2-mesh sieved soil was analysed for N, P and C. Total N was determined by the KJELDAHL method (BREMNER, 1960). Available P was determined by the Bray No. 1 method. Organic carbon was determined by the wet oxidation method (WALKLEY and BLACK, 1934). For total P, soil sub-samples were ashed in a muffle furnace at 550 °C for 1 h to 2 h. P was then extracted by placing the ash in sulphuric acid followed by shaking for 24 h. Total P in the filtrate was estimated by the ascorbic acid method.

Data analysis

Means for survival, height growth, DBH, basal area per ha, and wood basic density were subjected to analysis of variance (ANOVA). Data for percentage survival was transformed (arcsine) to remove bias (SOKAL and ROHLF, 1969). For significantly different treatments, the DUNCAN's Multiple Range Test was used for grouping of parameter means (STEEL and TORRIE, 1980).

An ordinal ranking scheme was instituted to show provenance score for each parameter. A mean score for significantly

Table 3. – Transformed (arcsine) mean survival percent of *Pinus oocarpa* and *Pinus patula* spp. *tecunumanii* (indicated by asterisks) provenances at Buhindi, Mwanza, Tanzania.

Provenance[x]	Age (yrs) 1	4	13	22
*CAM	61.8ab[y]	61.6a	56.8abc	54.7a
*YUC	59.2b	58.6a	54.9abc	53.1a
*RAF	64.1ab	61.8a	60.6abc	60.5a
*MPO1 (K49)	63.1ab	57.3a	55.1abc	54.6a
*MPO2 (K29)	64.9ab	63.5a	60.8abc	48.8a
ZAP	57.2b	56.8a	49.9c	49.6a
CON	66.7ab	64.2a	56.8abc	48.4a
JUN	71.4ab	69.5a	63.8abc	51.0a
BON	67.7ab	66.3a	65.9ab	55.7a
BUC	68.3ab	68.1a	67.1ab	56.1a
ANG	75.2a	67.9a	63.9abc	51.9a
ZAM	71.9ab	70.6a	67.9ab	57.4a
LAG	59.8ab	55.6a	55.1abc	49.1a
SIG	66.2ab	60.8a	54.3bc	51.7a
CHU	68.2ab	62.2a	58.6abc	50.8a
JOS	72.3ab	69.3a	64.6abc	53.7a

[x]) See *table 1* for acronym decoding

[y]) Means followed by the same letter within each column are not significantly different (P > 0.05).

Table 4. – Main height (m) development in *Pinus oocarpa* and *Pinus patula* spp. *tecunumanii* (indicated by asterisks) provenances at Buhindi, Mwanza, Tanzania.

Provenance[x]	Age (yrs) 1	4	13	22
*CAM	0.98ab[y]	6.34b	23.50a	29.66ab
*YUC	1.12a	7.36a	23.24ab	29.68ab
*RAF	1.05ab	6.52ab	22.26abc	30.28a
*MPO1 (K49)	0.99ab	6.53ab	21.62bc	30.16ab
*MPO2 (K29)	0.88ab	5.96b	21.30c	29.98ab
ZAP	0.91ab	6.11b	22.40abc	29.45ab
CON	0.90ab	5.59b	21.90abc	29.05ab
JUN	0.91ab	5.89b	22.96abc	29.96ab
BON	0.88ab	5.94b	21.64bc	28.17b
BUC	0.98ab	6.03b	21.86abc	29.92ab
ANG	0.86b	6.04b	22.26abc	29.13ab
ZAM	1.03ab	6.43ab	22.28abc	30.22a
LAG	0.85b	6.00b	22.76abc	29.95ab
SIG	0.92ab	5.81b	21.50bc	30.43a
CHU	0.84b	5.85b	21.26c	29.91ab
JOS	0.95ab	6.19b	21.30c	28.66ab

[x]) See *table 1* for acronym decoding
[y]) Means followed by the same letter within each column are not significantly different ($P > 0.05$).

different parameters, was used to show overall provenance performance.

Results

Survival

Survival of *P. oocarpa* at ages 1, 4, 13 and 22 is shown in *table 3*. Significant differences ($P < 0.05$) are evident in the first and third assessment. At 22 years survival before angular transformation varied from 77% Rafael (Nicaragua) to 56% Conacaste (Guatemala) however, there are no significant differences ($P > 0.05$) in survival between the provenances tested.

Height growth

Table 4 shows height growth trends. Significant differences ($P < 0.05$) were noted at all ages. At 22 years the outstanding provenances were: Siguatepeque (from Honduras), Raphael (Nicaragua), and Zamorano (Honduras). Least height growth was shown by the Bonete provenance from Nicaragua. The performance of other provenances tested varied between these two limits.

Breast height diameter growth

The DBH growth of the tested provenances was significantly different ($P < 0.05$) as shown by the two assessments (*Table 5*). Beginning with the best performing, DUNCAN's multiple range test (at 22 years) grouped the provenances as follows: Yucul; Camelias; Zapotillo; Mt. Pine Ridge (K29); Chuacus and Rafael, Angeles and Mt. Pine Ridge (K49), Siguatepeque, Junquillo, Bonete, Cinacaste, Zamorano, San Jose, Bucaral and Lagunilla.

Basal area development

Significant differences in basal area per ha ($P < 0.05$) were noted at the two assessment dates. At 22 years, the Bucaral (Guatemala) provenance was outstanding (*Table 5*). Least basal area development was found in the Conacaste, Lagunilla (Guatemala) and Siguatepeque (Honduras) provenances. The performance of the other provenances tested varied between these two limits.

Wood basic density and stem form

At 22 years, significant differences ($P < 0.05$) in wood basic density were detected. The highest density was recorded from the Bucaral (Guatemala) provenance (*Table 5*). Lowest performance was revealed by the Lagunilla (Guatemala), Yucul, Rafael, Camelias, Junquillo (all from Nicaragua) and the Angeles (Honduras) provenances. The performance of other provenances falls between these two limits.

No significant differences ($P > 0.05$) were detected in stem form at 22 years.

Discussion

Although survival assessments at 22 years gave no significant differences between the provenances tested, the Rafael (Nicaragua) provenance showed the highest survival. One of the major findings of the International Pine Trial Network, was the superior performance of several *P. oocarpa* provenances which upon closer investigation were subsequently reclassified as *P. patula* SCHIEDE and DEPPE ssp. *tecunumanii* (EQUILUZ and PERRY). In this study, the Camelias, Yucul, Rafael (Nicaragua) and the Mt. Pine Ridge K29 and K49 provenances

Table 5. – Mean breast height diameter (DBH), basal area and wood basic density of *Pinus oocarpa* and *Pinus patula* spp. *tecunumanii* (indicated by asterisks) provenances at Buhindi, Mwanza, Tanzania.

Provenance[x]	DBH (cm) at age .... yrs		Basal area (m^2 ha^{-1}) at ages ..... yrs		Wood basic density (kg m^{-3}) at 22 yrs
	13	22	13	22	
*CAM	23.2cb[y]	30.7ab	47.3abc	67.4ab	469b
*YUC	26.1a	31.0a	56.9a	68.4ab	463b
*RAF	24.0cd	28.6bcde	53.9ab	68.5ab	468b
*MPO1 (K49)	24.1bc	29.8abc	48.5abc	65.2ab	502ab
*MPO2 (K29)	23.1cb	29.0abcd	50.9abc	70.8ab	479ab
ZAP	24.2b	29.7abc	42.7bc	64.6ab	521ab
CON	23.6cb	28.0cde	48.2abc	54.2b	519ab
JUN	22.4bc	28.2cde	50.5abc	62.9ab	469b
BON	22.1c	28.1cde	50.6abc	67.3ab	494ab
BUC	22.5bc	27.5de	55.5ab	75.2a	542a
ANG	22.4bc	28.5bcde	50.5abc	54.8ab	468b
ZAM	23.1bc	27.9e	54.7ab	66.2ab	490ab
LAG	23.4cb	27.2e	51.8abc	54.6ab	463b
SIG	23.3bc	28.3cde	44.2c	62.6b	475ab
CHU	22.6bc	28.8bcde	46.7abc	64.1ab	476ab
JOS	23.7bc	27.5cde	54.2abc	63.3ab	484ab

[x]) See *table 1* for acronym decoding
[y]) Means followed by the same letter within each column are not significantly different ($P > 0.05$).

belong to that group (BIRKS and BARNES, 1990; POTTINGER, 1994).

This taxonomic revision has been viewed as antithetical in Forest Projects where *Pinus patula* is the main plantation species and *P. oocarpa* is viewed as an alternative species (MUGASHA *et al.,* in press). However as it has been shown above *P. caribaea* is exclusively planted at Buhindi, Rubya and Rubare in the Lake Victoria Zone, though not originally intended, the performance of *P. patula* ssp. *tecunumanii* in that zone is a positive development in the quest for species diversification.

Unlike survival, height growth varied significantly in all assessment dates. The outstanding provenances (at 22 years) were Siguatepeque (Honduras), Rafael (Nicaragua) and Zamorano (Honduras). It is worth noting therefore that performance of *P. patula* spp. *tecunumanii* does not always supersede that of *P. oocarpa.* This is further testified by the breast height diameter growth of the Zapotillo (Honduras) and Chuacus (Guatemala) provenances. Although the Yucul and Camelias (Nicaragua), Mt. Pine Ridge-K29 (Belize) and Rafael (Nicaragua) seem to be dominating performers, these two *Pinus oocarpa* provenances are also included among the best.

The scenario seems to repeat itself in basal area per ha development and basic density. It is worth mentioning that more than half of the natural distribution of *P. oocarpa* occurs outside Central America. Seed sources of the provenances used in this study (*Table 1*) do not cover that extended range. Since *Pinus patula* ssp. *tecunumanii* is now recognised as separate from *P. oocarpa* it is immediately apparent that provenances representation of this taxon is inadequate in this trial. This species is in most cases confined to higher altitudes than *P. oocarpa* and it is associated with mountains that form islands in the landscape. It is therefore of very discontinuous distribution and the five provenances distinguished in this study constitute a sparse sampling of *P. patula* ssp. *tecunumanii* (BIRKS and BARNES, 1990). Additional seed sources may be secured by reference to 18 additional sources recommended by STYLES and MACCARTER (1988). In that list 14 provenances are from Honduras, three from Guatemala, and one from Belize.

Thus viewed in the context of alternative afforestation species in the Lake Victoria Zone, considerable potential remains for experimentation and possible exploitation of both *P. oocarpa* and *P. patula* ssp. *tecunumanii* in terms of increased yield. However, given a big climatic range in the natural distribution of the latter species, considerable species-environmental interaction should be expected.

Present experimental limitations notwithstanding, it is now opportune to evaluate the overall provenance performance in terms of ordinal ranking scheme (*Table 6*). It can be observed that the list of the best seven performers are dominated by *P. patula* ssp. *tecunumanii.* There are however two interesting exceptions namely the Bucaral (Guatemala) and Zapotillo (Honduras) that are respectively the overall second and third best. This further indicates that although *P. patula* ssp. *tecunumanii* is generally outperforming *P. oocarpa* provenances, there are some exceptions thus further suggesting that diversification with *P. oocarpa* is possible.

Conclusion

Based on this study and restricting the subject to *Pinus oocarpa* provenances only, ranking in diminishing order of performance is Bucaral (Guatemala), Zapotillo, Zamorano (Honduras), Chuacus (Guatemala), Siguatepeque (Honduras), Bonete, Janquilo (Nicaragua), Conacaste (Guatemala), Angeles

Table 6. – Ordinal ranking of tree parameters showing differences between *Pinus oocarpa* and *Pinus patula* spp. *tecunumanii* (indicated by asterisks) provenances at Buhindi, Mwanza, Tanzania.

Provenance (Country)	Parameter and ordinal ranking score					
	Height	DBH	Basal area area	Wood basic density	Mean score	Overall score
*Mt. Pine Ridge (Belize) K49	4	3	8	5	5.00	1
*Mt. Pine Ridge (Belize) K29	5	5	2	9	5.25	2
Bucaral (Guatemala)	7	13	1	1	5.50	3
*Rafael (Nicaragua)	2	7	3	14	6.50	4
Zapotillo (Honduras)	11	4	9	2	6.50	4
*Yucul (Nicaragua)	9	1	4	16	7.50	6
*Camelias (Nicaragua)	10	2	5	13	7.50	6
Zamorano (Honduras)	3	13	7	7	7.50	8
Chuacus (Guatemala)	8	6	10	10	8.50	6
Siquatepeque (Honduras)	1	9	10	11	9.00	10
Angeles (Honduras)	12	8	13	5	9.50	11
Bonete (Nicaragua)	16	11	6	6	9.95	12
Junquilo (Nicaragua)	6	10	12	12	10.00	13
Conacaste (Guatemala)	13	12	16	3	11.00	14
San Jose (Guatemala)	15	13	11	8	11.75	15
Lagunilla (Guatemala)	14	16	14	4	12.00	16

(Honduras), San Jose (Guatemala), and Lagunilla (Guatemala).

It can also be added that suitability of *Pinus patula* ssp. *tecunumanii* provenances as an alternative species for *P. caribaea* at Buhindi indicates in descending order of performance, Mt. Pine Ridge (K49), Mt. Pine Ridge (K29), Rafael, Yucul and Camelias (Nicaragua) as alternatives.

Acknowledgements

We are grateful to Tanzania Forestry Research Institute for allowing us access to previous assessments; to Mrs. E. MTENGETI for analysis of soil samples and the Project Manager of Buhindi Forest Project for logistic support during final field assessments. We are also very thankful to Sokoine University of Agriculture for availing funds for final assessment, data processing and preparation of the manuscript.

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