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Characteristics of Photosynthesis and Respiration Rates in Strobili of *Pinus koraiensis* S. *et* Z.[1*]

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잣나무 毬果의 光合成과 呼吸의 特性에 關한 研究[1*]

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ABSTRACT

The dark respiration, photosynthesis(CO_2 refixation), CO_2 balance and chlorophyll content of 1st-year conelets and 2nd-year cones of Korean pine(*Pinus koraiensis* S.et.Z.) were investigated after pollination up to the end of maturation. The results obtained are as follows :

1. The growth of 1st-year conelet was 3.6cm in length, 2.4cm in diameter and 3.05g in dry weight during the first year. The growth of 2nd-year mature cone was 13.5cm in length, 9.3cm in diameter and 141.0g in dry weight in the late of 2nd-year.
2. The refixation of carbon dioxide released from a cone by the dark respiration was less than 50 percent at light saturation through the growing period. The refixation of carbon dioxide released by dark respiration for one year was 7.3 percent in 1st-year conelets and 8.7 percent in 2nd-year cones.
3. The dark respiration rate of cones by increasing temperature was rapidly increased with increasing temperature up to 25℃. The dark respiration rate of cones was much higher in non-growing season than that in growing season at the same temperature.
4. The rates of dark respiration and CO_2 refixation, based on the dry weight, were much higher in 1st-year conelet than that in 2nd-year cone.
5. The CO_2 balance for a cone was negative from pollination to the end of maturation. The net dark respiration loss for a cone was 7.23g CO_2/year in 1st-year conelet and 164.8g CO_2/year in 2nd-year cone.
6. The respiratory loss efficiency for a cone(=CH_2O weight calculated by net dark respiration/dry weight of cone) for one year was 1.61 in 1st-year conelet and 0.81 in 2nd-year cone for one year.
7. The tatal chlorophyll content of surface scale of the cone was lower than 2mg/g dw through the growing period, and chl. a/b ratio was 2 to 3.

Key words : *photosynthesis* ; *respiration* ; Pinus koraiensis *strobili*.

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要 約

잣나무 毬果의 生長에 따른 光合成速度(CO_2 再固定速度), 暗呼吸速度, CO_2 收支, 크로로필含量 등을 測定考察하였으며, 그 結果를 要約하면 다음과 같다.

1. 毬果는 當年에 길이 3.6cm 直徑 2.4cm, 乾重 3.05g까지 자랐으며 2年째에 길이 13.5cm, 直徑 9.3cm, 乾重 141.0g까지 자랐다.
2. 毬果의 暗呼吸에 대한 CO_2再固定率(光合成率)은 全生長期間동안 光飽和에서 50% 이하였다. 年間의 CO_2再固定率은 當年生毬果가 7.3%, 2年째 毬果가 8.7%였다.
3. 温度上昇에 따른 毬果의 暗呼吸速度는 25℃이하에서는 급격한 上昇을 보이나 25℃이상에서는 느린 上昇을 나타냈다. 같은 温度에서는 非生長期의 暗呼吸速度가 生長旺盛期보다 높았다.
4. 毬果의 暗呼吸速度와 CO_2再固定速度는 當年生毬果가 2年째 毬果보다 현저히 높았다.
5. 受粉後 完熟될 때까지 毬果의 CO_2 收支는 마이너스 값을 나타냈다. 年間 純呼吸消費量은 當年生毬果가 7.23 CO_2g/cone, 2年째 毬果가 164.8 CO_2g/cone이었다.
6. 年間呼吸消費效率(=純呼吸消費量/乾物重生産量)은 當年生毬果가 1.61이고, 2년째 毬果가 0.81이었다.
7. 毬果의 크로로필 a, b의 總含量은 全生長期間을 통해 2mg/g dw 이하였고, Chl. a/b값은 2~3을 나타냈다.

INTRODUCTION

It takes 2 years for Korean pine (*Pinus koraiensis*) cone to develop into mature cone after pollination. At the end of the first growing season the size of the conelet reaches to an average 35mm in length and 3 g in dry weight. Growth of the cone begins again in April of the following year. The average length and weight of a fully grown cone reached 142mm and 141 g respectively by September of the second year (Chon, 1977).

The mature seeds of Korean pine are usually used as a special food with high protein. The average number of seeds per cone is 136 and the total weight of seeds per cone is 80g (Chon, 1977). The cones requires a considerable amount of respiratory energy to maintain and accumulate a comparatively large volume of reproductive organs and seed protein during the development. The height and diameter growth of fecund trees of Korean pine is expected to be reduced a certain extent by the excessive loss of respiratory energy for the development of cones.

The reproductive organs such as fruits, flowers and cones are generally regarded as consumptive organs, but the cone of Korean pine contains chlorophyll and has a photosynthetic capacity. Thus it is considered that a lot of energy for cone growth can be supplied from the photosynthate of the cone itself. It has been reported by only a few authors that most conifer cones have some chlorophyll and a refixation capacity for carbon dioxide released from its respiration (Dickmann & Kozlowski, 1970; Rook & Sweet, 1971; Han & Suzaki, 1979; Linder & Troeng, 1981).

If the CO_2 balance between photosynthesis and respiration of the cone is positive, there is no affect to the growth of DBH and height, while if it is negative, there is not only reduction of growth of DBH and height but also accumulation of carbohydrate in the woody organs. Therefore, it is improtant to investigate the CO_2 gas exchange of cone itself as related to environmental factors.

This study was determined to investigate the characteristics of photosynthesis and respiration in the cones of Korean pine in relation to the dark respiration rate, CO_2 refixation, CO_2 balance per cone, chlorophyll content, and the seasonal changes of them.

MATERIALS AND METHODS

The sample cones were collected from 20-years old Korean pine trees which are in the campus of the Kangweon National University. An excised branch about 60cm with cone was taken and put it into the laboratory immediately in a water bottle and was cut again in a water bath, and then was kept in a water bottle during the measurement of photosynthesis and dark respiration. The changes of CO_2 concentration in the acrylic assimilation chamber (12cm×13cm×10cm or 13cm×23cm×13cm), in which the sample was enclosed, were measured by an infra-red CO_2 gas analyzer (ADC-225MK$_3$). The temperature in the chamber was maintained at a constant level (±0.1℃) from 5℃ to 40℃ by a water circulator (Yamato, CTE-22W). The cone surface temperature in the chamber was measured by a thermocouple and recorded by an automatic recorder (TOA, EPR-221A). The rate of air supply into the chamber was 4 ℓ/min. The air in the chamber was mixed by a fan with a velocity of 1m/sec. The chlorophyll content of cone surface was determined by the Omata & Murata's Method (Omata & Murata, 1981) which is improved from the Arnon Method (Arnon, 1945) using the UV-Spectro-photometer (CECIL, CE-599). This study was made from July 1986 to August 1987. Especially, the total monthly CO_2 balance of the cones was calculated by the rates of photosynthesis and dark respiration using the climatic data of monthly mean air temperatures and mean duration of sunshine in the recent 5 years in Chunchon area.

RESULTS AND DISCUSSION

1. Development of cone

Monthly changes in fresh and dry weight, relative water content, and length and width of the cones are shown in Table 1. Generally, the pollination occurs from late May to early June in the stand of Korean pine in Korea. During the first growing season, the conelets averaged 8.32g in fresth weight, 3.05g in dry weight, 3.6cm in length and 2.3cm in width. During the second year, the cone averaged 296.52g in fresh weight, 141.0g in dry weight, 13.5cm in length and 9.3cm in width. Especially the length and width of cones enlarged rapidly and nearly full size from early May to early June, and gradually increased up to maximum size in early September, while the dry weight increased gradually during the second growing season. These results were similar in the growth pattern to those of cone development of Douglas-fir (Ching & Ching, 1962) and Scots pine (Linder & Troeng, 1981). In the 1st-year conelets, the average relative water content was over 300 percent after pollination in June to July, but gradually reduced to about 170 percent in October. In the 2nd-year cone, the 189 percent in relative water content of the cone in March increased to 335 percent in early June, and then decreased gradually to 110 percent in early September. In the cone of the Douglas-fir, it was observed that the relative water content reached 400 to 500 percent on dry weight basis in mid May to early June and then reduced gradually to 150 percent in mid August (Ching & Ching, 1962).

Table 1. Development of cones after pollination in *Pinus koraiensis*.

Date	Fresh weight g	Dry weight g	Water content %	Length cm	Width cm
1986. 6.15	3.50	0.80	337.5	2.5	1.7
7. 3	4.76	1.16	310.3	2.8	2.0
8.22	8.56	2.49	243.8	3.2	2.4
9. 9	8.33	2.81	196.4	3.5	2.3
10.20	8.25	3.05	170.5	3.5	2.4
11.10	8.32	3.05	172.8	3.6	2.3
1987. 3.11	8.84	3.06	188.9	3.4	2.4
4.18	17.39	4.54	283.0	4.1	3.1
5. 7	36.12	9.02	300.4	5.7	3.9
6. 3	189.97	43.65	335.2	12.6	7.7
7.15	277.49	99.44	179.1	12.7	8.0
8.15	306.83	129.48	137.0	12.6	8.8
9. 2	296.52	141.00	100.3	13.5	9.3

* Each value is the mean of 20 cones.

The seasonal changes in relative growth rates of the cones are shown in Table 2. The relative growth rate of 1st-year conelets increased significantly with their development after pollination in July and decreased gradually during August and ceased in early September. The highest relative growth rate in dry weight of the cone was shown between May and June in the 2nd-year. During this period it showed 1.3g increment of dry weight per day and decreased significantly after July. The ratios of dry weight to fresh weight in 1st-year conelets and 2nd-year cones showed relatively low values from May to July, but these values increased again from August until early September. This result is similar to the observation by Linder & Troeng (1981) for the

Table 2. Mean relative growth rates(based on dry weight) of *Pinus koraiensis* cones.

Period	Relative growth rate (mg/cone/day)	Relative growth rate (g/cone/month)	Dry weight / Fresh weight
1986.6	26.7	0.80	0.29
7	42.9	1.33	0.24
8	11.6	0.36	0.29
9 1st-year	10.7	0.32	0.34
10 conelet	7.7	0.24	0.37
11	–	–	0.35
1987.3	–	–	0.34
4	235.8	7.07	0.26
5 2nd-year	1282.6	39.76	0.25
6 cone	1328.3	39.85	0.23
7	969.0	30.04	0.33
8	640.0	19.84	0.42
9	92.7	1.39	0.51

* Each value is the mean of 20 cones.

cone of Scots pine.

2. Seasonal variation of photosynthesis and respiration rates of cones.

For investigation the photosynthesis rates of the cones, the refixation rates of carbon dioxide by light intensity are shown in Fig. 1. When the dark respiration rate of the cone was given as 100 percent, the refixation rate of carbon dioxide increased with light intensity. The light saturation occures at about 30 Klux. The capacity of refixation of the cones at light saturation was approximately 40 percent of dark respiration in June, a vigorous growing season, and this rate was a little higher than in April. The refixation rate at light saturation was lower than those reported by Han and Suzaki (1979) for the cone of *Cryptomeria japonica*, which refixed remarkably above 100 percent of the CO_2 released by dark respiration of the cones and for the cones of Scots pine, in which the rate of refixation was approximately 50−75 percent during May to September(Linder & Troeng, 1981). As mentioned above, especially the low photosynthetic rate in the cones of Korean pine is due to the excessive consumption of respiratory energy to develop the bulky tissues of the cone and produce many seeds, so it needs to consume much photosynthate for respiration.

The relationship between dark respiration rate of the 2nd-year cone and temperature is shown in Fig. 2. The Arrhenius plots for the dark respiration rates in 2nd-year cones is represented as a convex curve at about 25℃. The rates of dark respiration in April were higher than the one in June in all the temperature ranges. The dark respiration rates of cones at various temperatures, based on the dry weight, were similar to other reports for the needles of Korean pine Han, 1982 and the results of 2nd-year cones of Scots pine (Linder & Troeng, 1981).

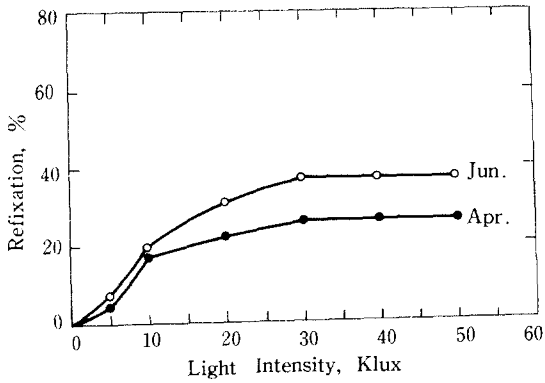

Fig. 1. Effects of light intensity on the refixation of carbon dioxide released by dark respiration in the cone of *Pinus koraiensis*. The values are shown as the percentage of the respiration rate in darkness. The sample is for 2nd-year cones in April and June 1987. Each point is the average of two measurements.

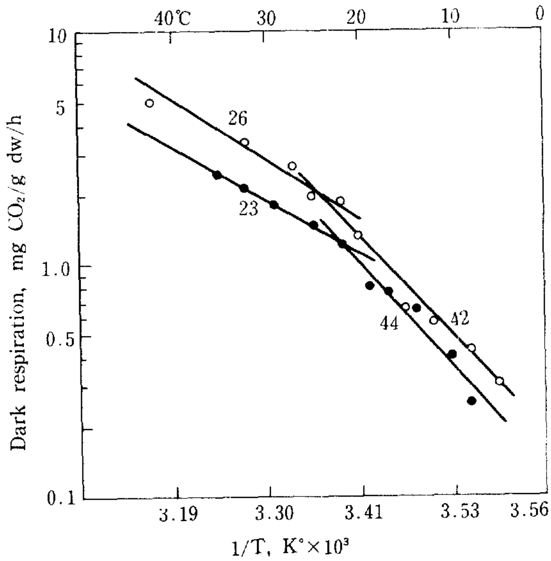

Fig. 2. Arrhenius plots for the dark respiration rate of 2nd-year cone in *Pinus koraiensis*. Open circle : April, filled circle : June.

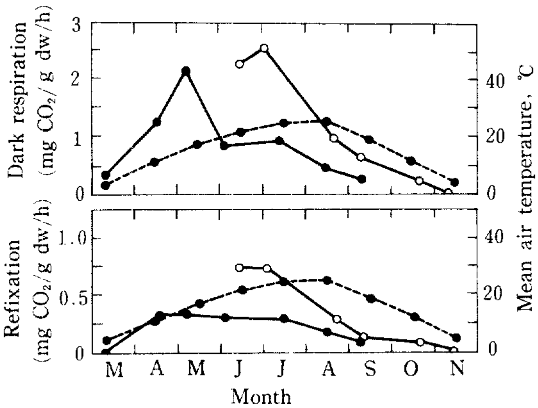

Fig. 3. Seasonal variation of dark respiration and refixation of the cone of *Pinus koraiensis* at mean air temperatures. Open circle : 1st-year conelet, filled circle : 2nd-year cone, broken line : mean air temperature. Each point is the average of two measurements.

The dark respiration rates increased very rapidly until 25℃ and then gradually increased over 25℃. Generally the dark respiration rate of cone at the same temperature was much higher in the nongrowing season than in growing season.

Seasonal changes of the dark respiration and refixation rates of carbon dioxide in cones of Korean pine are shown in Fig. 3. The dark respiration and the refixation rates of carbon dioxide released by dark respiration in 1st-year conelets were higher than those of 2nd-year cones. This result agreed with that of Scots pine(Linder & Troeng, 1981). As shown in Fig. 3, the dark respiration and refixation rates of carbon dioxide were variable during the growing season. The 1st-year conelets had the highest values from June to July, and then decreased remarkably. While 2nd-year cones had a constant refixation capacity from April to July then decreased gradually. The dark respiration rate of 2nd-year cones had the highest values in May, and thereafter tended to decrease with the maturation. A similar pattern of dark respiration was observed by Ching & Ching (1962) in the cones of Douglas-fir which had the highest values just after pollination and decreased rapidly thereafter.

3. Carbon dioxide balance of cone

For the purpose of finding the seasonal variation of CO_2 balance of cones, dark respiratory loss, CO_2 refixation, and net respiratory loss of carbon dioxide of cones were calculated using the monthly mean air temperature and duration of sunshine for the last five years in the Chunchon area(Table 3). There were much respiratory loss in the conelets from June to September. The values were especially high in July and low from September to November. CO_2 gas exchange was very rare during December to February. However, the net respiratory loss of cone was relatively high from June to September, and

Table 3. The monthly amounts of dark respiration, refixation, and net respiration in cones of *Pinus koraiensis*

Month	1st-year conelet			2nd-year cone		
	Dark respiration g CO_2/cone	Refixation g CO_2/cone	Net respiration g CO_2/cone	Dark respiration g CO_2/cone	Refixation g CO_2/cone	Net respiration g CO_2/cone
1	–	–	–	–	–	–
2	–	–	–	–	–	–
3	–	–	–	0.780	–	0.780
4	–	–	–	4.161	0.347	3.814
5	–	–	–	14.410	0.703	13.707
6	1.579	0.171	1.408	26.148	3.076	23.072
7	2.193	0.140	2.053	71.320	4.918	66.402
8	1.884	0.128	1.756	47.589	4.545	43.044
9	1.317	0.061	1.256	16.040	2.053	13.987
10	0.644	0.055	0.589	–	–	–
11	0.175	0.014	0.161	–	–	–
12	–	–	–	–	–	–
year	7.792	0.569	7.223	180.448	15.642	164.806

was highest in July. In 2nd-year cones, the respiratory loss increased rapidly from May, and showed the highest respiratory loss in July, and then decreased until August. However 2nd-year cones had a much higher CO_2 refixation rate from June to August.

During the first year, the amount of dark respiratory loss of CO_2 in conelets was 7.792g/cone and the refixation of CO_2 was 0.569g/cone so that the ratio of refixation of CO_2 was 7.3 percent. From this the net respiratory loss of CO_2 was determined to be 7.223g/cone. Therefore, a 1st-year conelet demands 7.223g CO_2 in net respiratory loss for 3.05 g dry weight growth. The carbohydrate of CH_2O can be calculated from CH_2O/CO_2, and it is 4.925g CH_2O during the first year. Thus the respiratory loss efficiency(CH_2O weight calculated by net dark respiration/dry weight of cone biomass=4.925/3.05) of the 1st-year conelet is 1.61. Consequently, the respiratory loss of carbohydrate in a 1st-year conelet is 1.6 times of the dry biomass of a conelet.

On the other hand, dark respiratory loss in a 2nd-year cone is 180.448g CO_2/cone, and the amount of refixation is 15.642g CO_2/cone. Consequently, the CO_2 refixation by photosynthesis in a 2nd-year cone was 8.7 percent. Therefore, amount of net respiratory loss of a 2nd-year cone is 164.806g CO_2/cone. The carbohydrate of respiratory loss in a 2nd-year cone is 112.368g CH_2O. Thus the respiratory loss in a 2nd-year cone is 22.8 times of a 1st-year conelet. The final dry weight of a cone of Korean pine is 141.0g(Table 1), the total dry weight of a cone biomass for only the 2nd-year growing season is 137.95g. From this the respiratory loss efficiency of the 2nd-year cone is 0.81. This means that the respiratory loss of carbohydrate is 81 percent of the dry biomass of a 2nd-cone.

During the lifetime of the cone of Korean pine, the total amount of respriatory loss is 188.24g CO_2, and total amount of refixation of carbon dioxide by photosynthesis is 16.211g CO_2, so that total amount of net respiratory loss is 172.029g. The refixation rate of carbon dioxide for the lifetime of a cone is 8.6 percent. From this it can be estimated that the amount of carbohydrate used during the lifetime of a cone would be 117.293g CH_2O. The respiratory loss efficiency of the cone of Korean pine during the period of a lifetime is 0.83. As calculated on carbohydrate(CH_2O), the respiration cost for cone production was 83 percent of final cone biomass of dry weight. Assuming a carbon content of 50 percent in the cones(Larcher, 1969 : Linder & Troeng, 1981), the carbon demand for the development of a cone during a lifetime would be : cone biomass 70.50g C, dark respiration 51.341g C, and amount of refixation of carbon by photosynthesis was 4.42g C. From this, the amount of net respiratory loss is 46.92g C.

Therefore, calculated on carbon, the respiration cost for Korean pine cone production was 73 percent of final cone biomass, and the average refixation for cone production by cone photosynthesis was only 8.6 percent. In Scots pine cone(Linder & Troeng, 1981), based on carbon, the dark respiratory cost for producing one cone was 72 percent of the final weight, in consequence of refixation by photosynthesis, this cost was reduced to 50 percent. On the other hand, a Korean pine produces 8.3 cones in average and occasionally up to 217 cones in maximum in a 45-year-old stand (641 tree/ha), which was investigated by Chon(1978). Based on the amount of CO_2, the amount of dark respiratory loss for cone production in a tree during a lifetime would be :

8.3×188.24g CO_2=1562.392g CO_2/tree, and the amount of refixation of CO_2 by photosynthesis would be :

8.3×16.211g CO_2=134.551g CO_2/tree. The amount of net respiratory loss for a tree would be 1427.841g CO_2 from this.

If the density is 641 trees per hectare in a 45-year-old Korean pine stand, the amount of dark respiratory loss would be 1,001.493 Kg CO_2/ha and the amount of refixation of CO_2 by phothosynthesis would be 86.247Kg CO_2/ha, so that the amount of net respiratory loss would be 915.246Kg CO_2/ha. Calculated on a carbohydrate basis the amount of dark respiratory loss would be 682.836Kg CH_2O/ha, and the amount of net respiratory loss would be 624.031Kg CH_2O/ha. Therefore, the net respiratory losses for annual cone preduction in a mature Korean pine stand would be about 973g CH_2O per tree and 624Kg CH_2O per hectare. In the case of 217 cones for a tree(Chon, 1978), it will greatly affect stem growth. Linder & Troeng(1981) reported that during a "normal" year, the dark respiratory loss for cone production equals 10−15 percent of the stem wood production. An annual stem growth in a 45-year-old stand of Korean pine is about 6.2ton/ha based on dry weight(Han et al., 1982), the 0.624 ton CH_2O/ha of dark respiratory loss for cone production per hectare equals 10 percent of the annual stem wood production. Therefore it is suggested that Korean pine tree improvement should proceed in two ways, one is to breed the trees with few cones for only stem production and the other is to breed the fecund trees for only seed prduction.

4. Chlorophyll content.

Seasonal changes in the content of chlorophyll a and b in the surface scales of cone of Korean pine are summarized in Table 4. The concentration of chlorophyll a and b is high from July to August in the 1st-year conelet but the lowest level in March in the 2nd-year cone. There is a constant chlorophyll a/b ratio through the growing season. Total chlorophyll content is 0.5−2mg/g dw during a lifetime. These value are relatively lower concentration than those in the needles of Korean pine, which was 2−4mg/g dw(Han & Yi, 1985). According to the results of Rook & Sweet(1971), the concentration of total chlorophyll was 0.762mg/g dw and the chlorophyll a/b ratio was 1.94 in Douglasfir cone.

Table 4. Concentration of chlorophyll in surface of cones of *Pinus koraiensis*.

Month	Chlorophyll (mg/g dw)							
	1st-year conelet				2nd-year cone			
	a	b	Total	Chl. a/b	a	b	Total	Chl. a/b
3	−	−	−	−	0.413	0.128	0.541	3.23
4	−	−	−	−	0.918	0.352	1.270	2.60
5	−	−	−	−	0.879	0.390	1.269	2.25
6	−	−	−	−	1.105	0.481	1.586	2.30
7	0.972	0.480	1.452	2.03	1.215	0.473	1.688	2.57
8	1.020	0.580	1.600	1.76	1.397	0.583	1.980	2.40
9	0.747	0.243	0.990	3.07	1.126	0.456	1.672	2.67
10	0.593	0.291	0.884	2.04	−	−	−	−
11	0.547	0.266	0.813	2.06	−	−	−	−

Oku(1975) reported that the total chlorophyll content was 3.29mg/g dw in the needles of *Pinus densiflora*, 2.06mg/g dw in the needles of *Cryptomeria japonica*. Also the chlorophyll a/b ratio was 2.24 in the needles of *Cryptomeria japonica* and 3.79 in the needles of *P. thunbergii*. Therefore it was found that the concentration of total chlorophyll in the surface scales of cones of Korean pine was considerably lower than that of the needles, while it is slightly higher than that of the Douglas-fir cones.

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