Study on the Seed production of Japanese Red and Black Pine (1)*

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アカマツとクロマツの種子の生産量に関する研究

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摘　要

アカマツおよびクロマツの種子の生産量を推定することを目的にこれらの種子に関する調査を京大上賀茂試験地と滋賀県日野のマツ林で1972年9月から1973年5月まで毎月おこなった。母樹上に存在する球果の種子の変動の調査も上記の期間におこなった。100-130個の球果を色々の高さのアカマツおよびクロマツの木から採取して球果あたりの種子数と種々の要因との相関関係などを求めた。さらに樹脂含有率と球果の開度（球果の短径／球果の長径）との関係もしらべた。その結果は次のようであった。

1) 球果の中の約20%以上の種子は12月落下し，その後は徐々に減少してゆくようである。

2) 10～12月の3回にわたって調査した相関関係数の平均値は次のようであった。

	クロマツ	アカマツ
種子数一球果乾重	0.85	0.72
種子数一球果の長さ	0.78	0.54
種子数一鱗片の数	0.65	0.72
球果の長さ一鱗片の数	0.91	0.66
球果の長さ一球果の乾重	0.79	0.78
種子の重さ一球果の乾重	0.77	0.71
球果の乾重一鱗片の数	0.71	0.64

3) 鱗片の樹脂がアカマツおよびクロマツの球果の不開性 (Serotiny) の原因となる。

4) クロマツの球果の開度と残留種子数との相関関係は−0.77であった。

5) クロマツ種子の一部は球果の開閉運動によって破損し発芽能力がうしなわれる。

* Contribution from JIBP-PT, 178

Abstract

For estimates of seed production of P. densiflora and P. thunbergii, fundamental study of cones was carried out at Kamigamo and Hino forest sites for the period beginning October 1972 to May 1973. Monthly changes of the remaining seeds in the cones was investigated during the same period. 100–130 cones were sampled from trees of various size, and regression analysis between seed number and other factors was carried out. Resin content of cones was also estimated by extraction with benzene-alcohol mixture solution. The results obtained were as follows:

1) About 20% or more of pine seeds in cones fell during December and after that decreased steadily, and April's results showed that about 4% of seeds in Japanese red pine and 7% in black pine remained in the cones.

2) Regression analysis obtained from various factors is as follows:

factors	black pine	red pine
seed number and cone weight	0.85	0.72
seed number and cone length	0.78	0.54
seed number and scale number	0.65	0.72
cone length and cone weight	0.79	0.78
cone length and scale number	0.91	0.66
seed weight and cone weight	0.77	0.71
cone weight and scale number	0.71	0.74

3) The results of resin analysis showed that the resin of the scales is responsible for cone serotiny of red and black pine.

4) The correlation coefficient between the opening degree and number of remaining seeds in cones of Japanese black pine was −0.77.

5) It was found that some seeds are smashed to break during the opening and closing movement of the cone in the Japanese black pine.

Introduction

For the study of regeneration of Japanese red and black pine, it is necessary to estimate seed production from a stand; many attempts have been made, but they show that this kind of old method of seed trapping is impractical. Actually, it is difficult to estimate the seed production of individual trees. So it is necessary to investigate the seed number and seed locations from individual cones. In coniferous species the cone shape of one is different from other species. For example, the white pine (P. strobus) has a long cone compared with basal diameter, but the Japanese red pine (P. densiflora) and black pine (P. thunbergii) have comparatively round cones. So in the case of Japanese red and black pines, other than cone length materially improve estimates. A method of estimating seed fall from the cone counts of seed locations on individual cones is proposed by Harold W. Hocker.[1]

In general, the release of seed is a far more protracted process than is commonly supposed. Especially cones with a high resin content, which is secreted from various points on the cone and runs down over the scales in irregular driblets, fail to open. Cones which have thick scales are poor in their opening properties, while cones with thin scales do well. The middle portion of scales, where most of the seeds are located, tends to open easily. The top and basal part of cones have difficulty. It would be interesting to find out the factors which improve estimates of seed production and the relation between resin content and opening degree. Monthly changes in the remaining seeds in the cones were investigated.

Methods of study

During the period 20 October 1972 to 20 May 1973, each month a total of 100–130 cones were harvested from pine trees of various size. The number of seeds in the cones was calculated by the seed print and this method proved very effective in the calculation of seed number. The scales of the cones were removed individually in order to know the seed print. The number of seeds remaining in the cone was determined in the same way as the method of determining total seed number.

A tree's cones vary in size, weight and shape, and each tree has different properties genetically and physiologically. The size of the mature cones may vary according to position on the tree, exposure, nutritional factors or general tree vigor.[2] On the assumption that the reliability of data increases with the sample size, the cones of P. thunbergii and P. densiflora were sampled from various trees as conditions permitted at Kamigamo and Hino experimental sites. Cones sampled were analyzed using nipper, pincette and tally counter. Wet cones were kept in the laboratory at room temperature for three days after which their long and short diameters were measured.

For the estimation of the resin content of a cone, it was divided into three parts; wing, scale and cone body. Generally ethyl-ether, acetone and alcohol-benzene mixture solution were used as resin extraction solvents.[3,4] In this experiment benzene-alcohol mixture solution was used. In general, the extractives consist of resin, oils, fats and fatty acids and some inert matters. But the contents of oils, fats, fatty acids and some other inert matters other than resin are so small that they may be disregarded. The dry matter of the cone was obtained by placing the cones in drying oven at 80°C for one week. The opening degree was obtained from the ratio of the short and long diameters of the cone. The thickness of cone scales was measured at the top and the proximal part using caliber meter.

Results and discussion

Each species has a different thickness of scale. But the same species is characterized by the thickness of scale regardless of its cone size (Table 1). So species with thin scales will open well compared with species with thick scales when mature. Table 1 shows that the scale of P. thunbergii is thicker than that of P. densiflora.

The number of seeds in the cones grown on different trees varied from 6 to 88 in P. thunbergii and from 8 to 107 in P. densiflora and it was found that the distribution of seed number is very similar to the normal distribution curve and particularly that maximum frequency appears at class 40–50 and 60–70 in the case of red and black pines respectively when the class interval is provided with unit 10, expressed in the number of seeds. The results of this experiment showed that the black pine has heavier seeds than those of the red pine. This result is agreed by Miyake at al.[5,8,9,10] The cone weight of the red pine ranged from 1.6 to 9.3 g and 5.5–26.0 in the black pine. Cone length varied from 22 to 55 mm in P. densiflora and from 37 to 72 in P. thunbergii (long diameter). The range of scale numbers of cones was 62–107 in red pine and 71–105 in black pine respectively. There was no difference of scale number between red pine and black pine, which means that the scale of the red pine is smaller than that of the black pine.

Table 1. The thickness of cone scale in *Pinus densiflora* and *P. thunbergii*. (mm)

Se. No	*P. thuubergii* long diameter (mm)	TS U	TS P	MS U	MS P	BS U	BS P	*P. densiflora* long diameter (mm)	TS U	TS P	MS U	MS P	BS U	BS P
1	40	3.1	1.5	3.0	1.3	2.6	1.2	39	1.3	1.0	2.3	0.9	2.3	1.0
2	41	2.9	1.2	3.2	1.2	3.1	1.3	36	2.4	0.9	2.9	1.0	2.6	1.0
3	39	3.1	1.1	3.3	1.6	3.0	1.5	35	2.3	0.7	2.1	1.3	2.4	1.1
4	37	3.2	1.0	3.0	1.6	2.9	1.4	34	2.1	0.9	2.5	0.9	2.3	1.1
5	43	2.7	1.2	3.1	1.3	3.4	1.5	32	2.4	1.0	2.2	0.8	2.5	1.1
6	49	3.4	1.4	3.0	1.5	3.4	1.7	33	1.8	1.1	1.9	0.9	2.5	1.2
7	48	2.9	1.1	2.9	1.5	2.7	1.3	36	2.7	1.0	2.5	1.1	2.7	0.8
8	50	2.5	1.4	3.4	1.6	3.5	1.5	39	2.5	1.4	2.9	1.3	2.7	1.4
9	50	2.8	1.7	3.2	1.6	3.2	1.2	39	2.2	1.1	2.1	1.0	2.7	0.9
10	49	2.6	1.2	2.8	1.3	2.9	1.5	33	2.0	1.0	2.1	1.1	2.5	1.4
11	51	3.0	1.5	2.8	1.4	3.3	1.4	37	2.0	1.0	2.7	1.0	2.8	0.9
12	54	2.9	1.4	3.2	1.2	3.7	1.5	34	2.1	1.0	2.5	1.2	2.7	1.4
13	49	3.1	1.3	3.0	1.4	2.9	1.4	33	2.3	0.9	2.5	0.9	2.9	1.1
14	59	3.4	1.4	3.2	1.2	3.0	1.3	40	2.0	1.4	3.1	1.1	2.7	1.5
15	60	3.2	1.1	3.1	1.3	3.0	1.3	36	2.5	0.9	2.6	1.1	2.4	1.0
16	46	3.4	1.6	2.7	1.4	3.7	1.5	37	1.5	0.9	2.1	1.0	1.7	0.9
17	43	2.8	1.3	2.9	1.4	3.1	1.2	33	1.9	1.0	2.2	1.1	2.3	1.2
18	68	3.3	1.4	3.3	1.5	3.1	1.4	37	1.6	1.0	2.2	1.2	2.4	1.1
19	62	3.0	1.1	3.2	1.2	3.1	1.3	36	2.1	1.1	2.3	0.9	2.4	1.1
20	60	3.0	1.2	3.3	1.2	2.9	1.3	30	1.6	1.2	1.9	1.2	2.4	1.1

TS: Scale of top portion MS: Scale of middle portion BS: Basal scale.

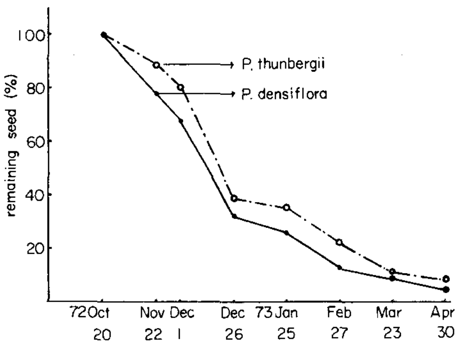

Fig. 1. Monthly change of remaining seeds in the cones.

It is usual in Japan for occasional seeds to have been found in the cones as late as August of the following year. The cones, as they dry ripen in October in Japan, turn from green to brown and finally as they dry out and begin to open. In the case of P. banksiana, the majority of seeds are retained for many years in the persistent cones and normally, unless a forest fire sweeps through the stand, do not escape in large numbers.[6] There are many factors affecting the opening of cones. A combination of low precipitation, low humidity and high temperature and less resin seems to be necessary to cause the cones open.

The cones of Japanese red and black pine in Japan ripen late in October and fall slow and continuously until November. About 20% or more of total seeds fall during

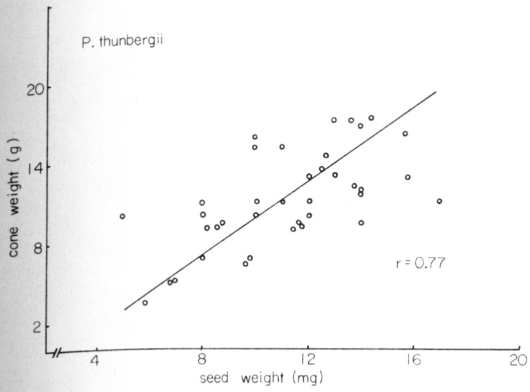

Fig. 2. Relation between seed weight and cone weight in Pinus thunbergii.

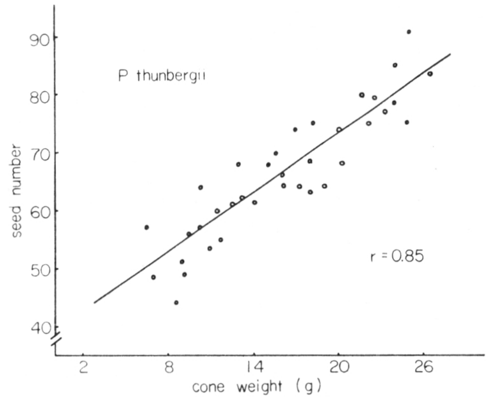

Fig. 3. Relation between cone weight and seed number in Pinus thunbergii.

December and after that decrease steadily (Fig. 1). Late in February, 12% of seeds in red pine and 22% in black pine remained in the cones. The black pine takes longer to release seed than the red pine. It is supposed that this is why the Japanese black pine has thicker scales than the red pine (Table 1).

Regression analysis was carried out to determine whether or not there was a relation between seed number locations and other factors. The relation between seed weight and cone weight is shown in Fig. 2. The correlation coefficient was 0.77 in black pine and 0.71 in red pine respectively. It has been known that thick scale is responsible for a serotinous cone, but this result show that the same species has no difference in thickness of scale of P. densiflora and P. thunbergii. So in the case of the same species the thickness of scale has no relation to the opening degree of cones (Table 1). Resin analysis shows that the resin content of cones has significant relation to the opening degree (Fig. 10).

The serotiny of red and black pine is not so influential in natural regeneration. Serotinous cones, including top serotinous cones occupies 7% among the total number of cones. If top serotinous cones are including, it reaches 22%. Considering the data

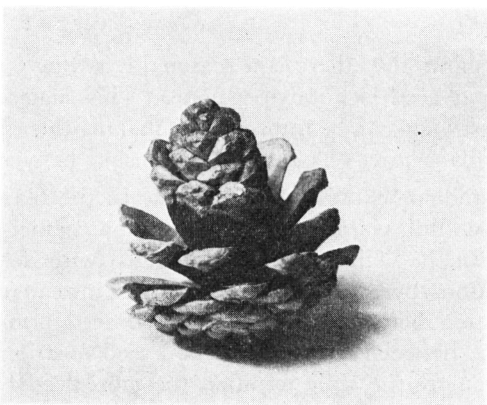

Photo 1. Serotinous cone of Pinus thunbergii. This serotiny is responsible for remaining seeds in Japanese red and black pine. Resin is characterized by white spot.

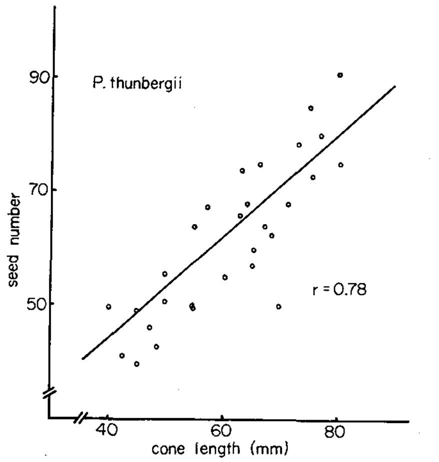

Fig. 4. Relation between cone length and seed number in Pinus thunbergii.

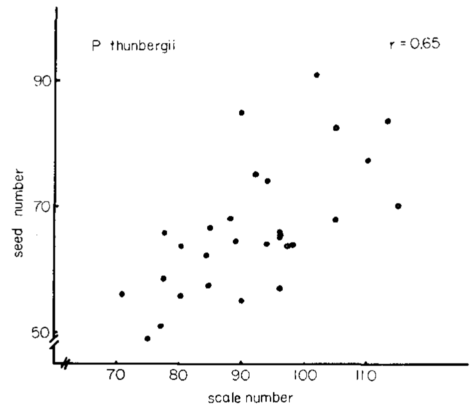

Fig. 5. Relation between scale number and seed number in Pinus thunbergii.

mentioned above, the percentage of serotiny in Japanese red and black pine is lower than that of the lodgepole pine in America and the importance of serotiny in Japanese red and black pine is not as serious factor as in the case of lodgepole pine. As the serotiny continues as late as August of the following next year, the seeds of the top serotinous cones fail to be released and have no meaning for natural regeneration. The opening and closing movement is similar to the synchronous type. Occasionally some seeds are smashed and break due to the opening and closing movement in the case of P. thunbergii. Moreover pine seeds sometimes fail to be released because of spiders webs. The percentage of scales containing seeds was 35% in red pine and 32% in black pine. It was supposed that one scale has two seeds but in fact two-seed scales were 22.4% in black pine. It was found that only small proportion of scales have seeds in them. A cone theoretically has the potential for producing two seeds for every scale or twice as many seeds as scales, but ovules in the proximal portion and top of cone are structurally unable to produce seeds. Abortion of ovules within the productive region of a cone is 65% in Japanese red pine and 68% in Japanese black pine. But Pinus resinosa in America showed 20%.[7]

Analysis of the data shows that there is a reasonably strong correlation between cone weight and the number of seed locations per cone. This suggests that if the regression equation is known, the estimate can be improved by making the relatively simple measurement of weight in the black pine. A linear relationship between the number of seeds and cone volume was studied by Dickerman et al.[2] In the black pine, inasmuch as a light cone may contain no full, viable seeds, a correlation coefficient(r) of 0.85 was found for this relationship. But the white pine (P. albicaulis) with it long diameter, it is easy to determine seed locations by measuring cone length instead of cone weight. There is a reasonable correlation between cone length and seed number (r=0.78) and this value is lower than that between cone weight and seed locations (Fig. 4). In general it may be said that the more the scale number, the more seeds. But in fact the coarse relationship between scale number and seed number is shown (Fig. 5). Consequently, the correlation between number of scales per cone and number of seeds per cone was 0.65 in Pinus thunbergii and 0.72 in Pinus densiflora. The result of Pinus thunbergii coincided with that of Pinus resinosa (r=0.64).[2] And the points along the regression line were

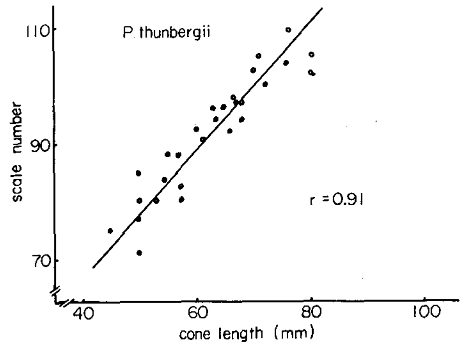

Fig. 6. Relation between cone length and scale number in Pinus thunbergii.

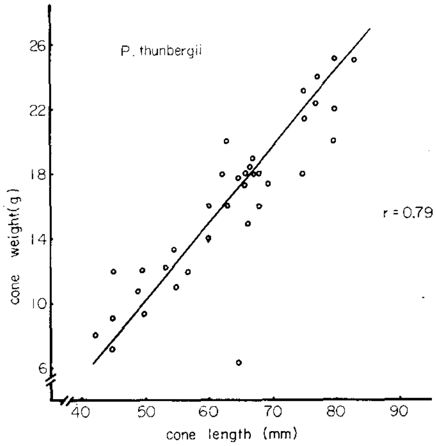

Fig. 7. Relation betewen cone length and cone weight in Pinus thunbergii.

widely scattered. Thus, the number of seeds produced by cones of red pine and black pine appears not to be highly dependent on the number of scales.

In estimating scale number in black pines, cone length is more effective than that of cone weight (Fig. 5 and Fig. 9). Seeds which are adapted to dissemination by wind vary greatly with factors such as, weight, shape, area, wing and the combined effect of the factors mentioned above. In general one may say that species producing heavy seeds tend to have a faster rate of fall than those producing light seeds. But seed weight is not the determining factor. In some species there seems to be some evidences of a slight negative correlation between weight of seed and rate of fall.[11,12] But in genus Pinus the rate of fall is positively correlated with the average weight of the seed. In terms of dissemination it is supposed that a heavy cone is disadvantageous.

Resin analysis of the cone (wing, scale and cone body) is as follows. Resin content of P. thunbergii is higher than that of P. densiflora. The result revealed that scale is the most, cone body is next and wing is the least in resin content. It is supposed that cone resin of P. thunbergii and P. densiflora is responsible for the closing of the cone. Serotinous cones of P. contorta do not open at maturity because of resin bond between

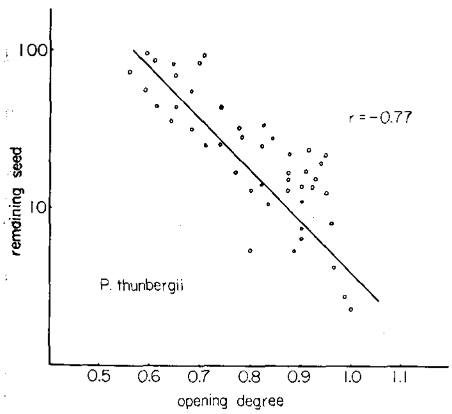

Fig. 8. Relation between opening degree and remaining seed in Pinus thunbergii.

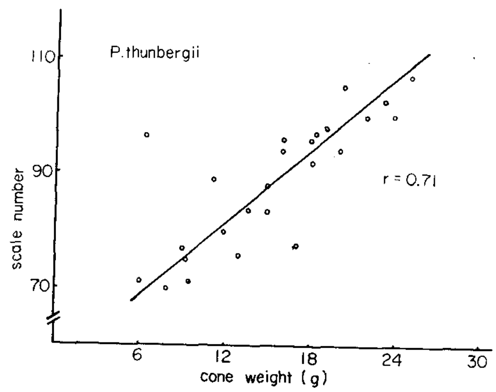

Fig. 9. Relation between cone weight and scale number in Pinus thunbergii.

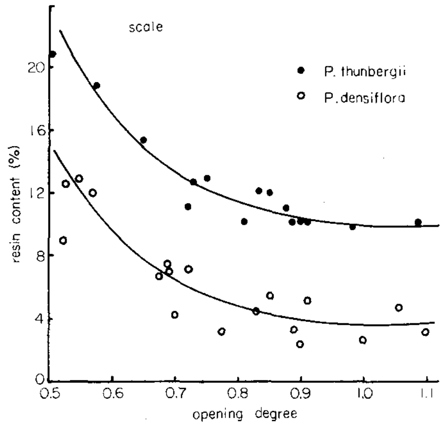

Fig. 10. Relation between opening degree and resin content of cone scale.

the cone scales. When it is subjected to temperature of 45°C to 50°C, the resin bond breaks, the cones open, and the seeds stored for several years are released. It is interesting that the relation between the opening degree and remaining seeds in cones shows a negative correlation ($r = -0.77$) (Fig. 8). A relationship between resin content of scale and opening degree was shown in the Fig. 10. We may pick up several factors concerned with opening phenomena of cones from the view point of physiology, physical conditions and genetics. It is revealed from this experiment that resin content is the most important factor which controls the opening of cones in Japanese red and black pines.

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