Seasonal Changes of Chemical Components in the Cones from Various Clones of *Abies sachalinensis* in a Seed Orchard and Germination Test of the Mature Seeds

By

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採種園産のトドマツクローン球果成分の季節動態と完熟種子の発芽試験

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Abstract

Cones were collected from eight specimens of *Abies sachalinensis* including six clones monthly from May to September, and the changes of dry cone weight and various chemical components in the cones were traced, using seed and scale separated from cone for the cones collected after July. Variations of mature cones from the 36 trees including eleven clones were also investigated chemically, and the relation between germination rate and each quantity of chemical components per grain of seed was examined. Cone weight inceased from about 160 mg in May to 12,300 mg in September on the average. Although the percentages of nitrogen, total minerals, phosphorus, and potassium in the cones fell rapidly in the course of their growth, these substances taken up in the cones increased remarkably. Calcium content was unexpectedly low, compared with that of magnesium. Average germination rate of mature seeds was 29%, and seeds from the same clone showed similar germination rate as well as weight and the proportions of chemical components. The germination rate had a highly positive relation to the weight and the quantities of chemical components per grain of seed except calcium—especially potassium, nitrogen, and minerals—as indicated by the high values of the coefficients of correlation.

Key words: *Abies sachalinensis*, Clone, Cone, Chemical component, Germination.

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Contents

Introduction

Compared with agricultural crops or fruit trees, forest trees are close to wild plants and have highly diverse genetic variations within a certain species. Timber production, for example, may take several decades, during which time the trees often suffer from meteorological disasters and insect and fungal injuries.

Meanwhile, because the timber imports to Japan may be curtailed in the near future, owing to deterioration of the global environment as well as to cutting restrictions designed to preserve tropical rain forests, it is essential to prepare requisite amount of timber in Japanese forests. It is, accordingly, still more important to practice afforestation of good quality trees with steady and healthy growth and well-adapted to regional conditions, in the event of a long forestry depression.

With this view in mind, the Japanese Forestry Agency has been involved in tree breeding since 1956. In Hokkaido national forests, many specimens of *Abies sachalinensis, Picea glehnii,* and *Larix kaempferi,* the most popular planting species in Hokkaido, have been selected as elite trees of phenotype by mass selection in natural and artificial forests. The scions of these trees were grafted and the resultant clones had been planted in seed orchards since 1961. In the near future, afforestation can be conducted with the seedlings cultivated from the seeds of the clone trees.

The present study was performed, in order to grasp the growing process of the cones from the clone trees as well as monitor the germination power of the mature seeds. Seasonal changes of cones have hardly been reported to date, except for those of the genera *Pinus*[1,5,6] and *Cryptomeria*[7]. The authors collected cones cross-pollinated with various clones of *Abies sachalinensis* in the Hattari Seed Orchard in southern Hokkaido monthly from the first stage to maturity, and recorded the seasonal changes in cone weight and the contents of chemical components in the cones through their growth. Moreover, the authors collected many kinds of the mature cones and analyzed their chemical components, as well as examined the germination power of the seeds in a nursery field. Parts of this study have been reported in the proceedings of the Meeting of the Japanese Forestry Society[3,4,8].

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Outline of the Seed Orchard[2]

There are 45 seed orchards belonging to Hokkaido national forests, one of which is the Hattari Seed Orchard, founded in 1962 from a previous nursery. This seed orchard, located on plains about 5 km east of the coast of the Sea of Japan (Fig. 1) in Kyowa Town, Iwanai County, was chosen on to provide excellent seeds of *A. sachalinensis* for afforestation in southwestern Hokkaido. As for climate, the annual mean temperature is 8.5℃, yearly precipitation has been 1,183 mm on the average of the last ten years,

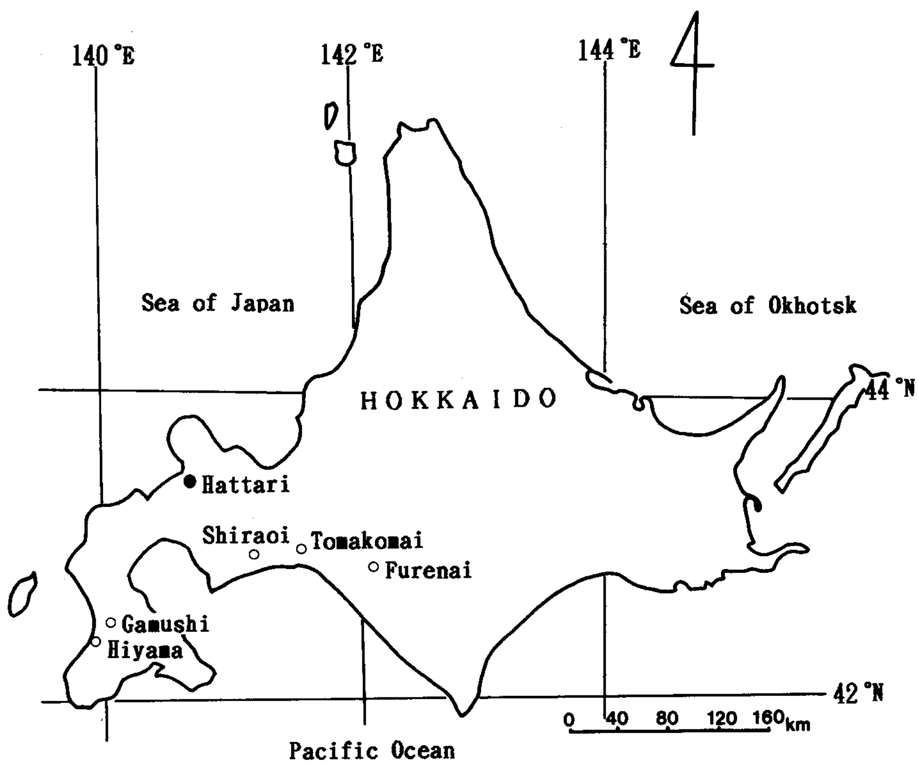

Fig. 1. Location of the Seed Orchard (●) for collection of cones and places of elite trees for cultivation of clones (○).

and strong westerly winds blow with occasional snowstorms in the winter. The soils, as shown in Table 1, are divided into A, B_1 and B_2 horizons at Site No. 9, and A, B at Site No. 4 using the naked eye, and are generally loamy, Drainage is good at No. 9 but not at No. 4 in spite of its rich gravel. The solid rate in volumetric proportion of three-phase is extremely high at both sites, because this land, which consists of old dry riverbeds, has been ameriolated and tightened through the reclamation with new mixed soils.

Since 1962, the planting of *A. sachalinensis* clones had been underway with an arrangement in 9-type of 3×3, which was changed to 49-type of 7×7, owing to the increase in clones after 1967. Planting was completed in 1970, and now the planting area and the planting number are respectively 7.56 ha and about 7,000 trees of 114 clones, consisting of 51 clones derived from natural forests (three-figured number behind the name of place where elite trees are selected) and 63 clones from artificial forests (one-figured number). In the management of the orchard, compound fertilizer (N : 7.5%, P : 4.5%, K : 5.0%) is given at 500 g per tree every year and agricultural chemicals are occasionally sprinkled as needed. The fruiting of cones began in 1971, and good harvests have been reaped every three to four years. In 1981, 37,700 cones were harvested from which 754 kg of refined seeds were obtained, while in such lean years as 1975 and 1980 no seed was obtained at all.

Material and Experimentals

1. Material

In order to investigate the seasonal changes of chemical components in the cones, samples were collected from eight

Table 1. Physical properties of soils in the Hattari Seed Orchard

Plot	Horizon	Depth (cm)	Thickness (cm)	Soil class	Color		Hardness		Structure	Gravel (%)	Apparent specific gravity		Moisture (%) based on		Distribution of three phases (vol.%)			Porosity (vol.%)
					Munsell	Naked eye	Tester (mm)	Consistency			Fresh soil	Dried soil	Fresh soil	Dried soil	Solid	Liquid	Gas	
Site No. 9 planted in 1968	A	0–22	22	SiL	7.5YR3/3	Dark brown	20	Hard	Granular	2	1.26	1.02	22	28	40	25	35	60
	B_1	22–45	23	CL	7.5YR4/6	Drown	20	Hard	Crumb	2	1.69	1.37	19	24	53	31	16	47
	B_2	45~	—	SL	7.5YR5/6	Bright brown	18	Hard	Blocky	14	1.94	1.57	19	24	60	37	3	40
Site No. 4 planted in 1964	A	0–35	35	CL	5 YR3/2	Brownish black	14	Medium	Crumb	45	1.26	0.88	34	51	34	38	28	66
	B	35~	—	SL	7.5YR/4/4	Brown	19	Hard	Blocky	49	1.40	1.16	21	27	45	29	26	55

individual *A. sachalinensis* trees planted on Site No. 9 of the Hattari Seed Orchard in 1968, consisting of six clones (Furenai 102, Gamushi 5, Gamushi 103, Hiyama 9—① and ②, Tomakomai 3—① and ②, and Tomakomai 4, as shown in Fig. 1). Two or three cones per tree in five growing stages were collected from May (unpollinated strobilus stage) to September (mature cone), in 1983 (on May 6, June 10, July 15, August 9, and September 6). The cones were dried and prepared for weighing and chemical analyses, then separated into seed and scale including axis after the July collection. Meanwhile, mature cones were collected in September 1983 from 36 individual trees consisting of 11 clones, and prepared for weighing, chemical analyses and germination tests of seed. The grade of the cone harvest in 1983 was said to be a lower-medium.

2. Experimentals

Weighing and chemical analyses…Average cone weights were determined after drying in a 105℃ oven. The weight of the cones collected from July to September, including 36 kinds of mature cones was calculated by the sum of whole seed and scale weights, in which the seed number per cone was counted and the percentage of seed weight per cone was also calculated. After the cone, seed, and scale were pulverized, carbon and nitrogen were determined with a C-N Corder, while total mineral content was determined by ashing in a 600℃ electric furnace. Using the minerals dissolved with 10% hydrochloric acid, phosphorus was determined by the vanado-molybdate method with a spectrophotometer at 440 nm. Potassium, magnesium, calcium, and sodium were determined using the same solution as above with an atomic absorption spectrophotometer. For magnesium and calcium determinations, a strontium solution was added to 1,000 ppm. Those determined were expressed as oxide. The contents of chemical components were calculated in percentages to cone, seed, or scale weights and quantities per cone, whole seed and scale in a cone or grain of seed (dividing whole seed weight by seed number per cone).

Germination test…Refined seeds buried in the field of the Hokkaido Forest Tree Breeding Institute during winter were used for the germination test in April 1984. Each five-gram seed, whose number was obtained with each average grain weight, was sowed on the nursery with three replications. The germination rate was calculated by counting seedlings germinated two months afterward, in which damping-off rarely occurred. The coefficients of correlation were also calculated between the quantities of two chemical components per grain of seed and between germination rate and each of the quantities.

Results and Discussion

1. Seasonal changes in cone weight

Seasonal changes in cone weight are shown in Table 2 and Fig. 2. By the first collection, May 6, the weights had all exceeded 100 mg, and the average of the cones (unpollinated strobili) collected from eight individual trees on May 6 was 157 mg. The maximum of 215 mg, Gamushi 5, was about twice as heavy as the minimum of 118 mg, Hiyama 9—①. On June 10, the average weight reached 3,360 mg, which was 20 times as heavy as the former average. The range was between 2,387 mg for Tomakomai 3—① and 5,834 mg for Tomakomai 4, the increment of which was remarkable. The weight of cone expressed with the sum of seed and scale was 8,547 mg on the average for the third collection, July 15, in the range from 4,364 mg (Tomakomai 3—②) to 11,714 mg (Tomakomai 4). The average weight of seed in the third collection was 1,703 mg, which accounted for just 20% of cone, while that of scale was 6,843 mg. The seed number per cone, first counted separately, was 301 grains on the average, so the grain weight was 5.56 mg. The average of the cones collected on August 9, the fourth collection, was 10,700 mg, the value of which showed a small increment (1.25 times) compared with the former of 8,547 mg, and the range was from 6,067 mg (Tomakomai 3—②) to 14,521 mg (Tomakomai 4). The seed weight was 2,749 mg, accounting for 26% of cone, indicating that the growth of seed was more than that of scale. The average grain weight reached 9.03 mg, equivalent to 1.6 times the former weight of 5.56 mg. The average weight of the mature cones collected on September 6, the last collection, was 12,292 mg, the least increment ranging between 7,259 mg (Tomakomai 3—②) and 17,033 mg (Tomakomai 4). The light cones in the first stage were insufficiently developed to the end through their growth, while the heavy ones were fully mature in the last stage. The average weight of seed was 3,273 mg, accounting for 27% of cone and 1.2 times the former weight of 2,749 mg.

Table 2. Seasonal changes in dry weight of cones from various clone trees (mg)

Collected date		May 6	June 10	July 15					Aug. 9					Sept. 6				
Clone		Cone	Cone	Cone	Seed	(Seed number/Cone)	Grain (10^{-2})	Scale	Cone	Seed	(Seed number/Cone)	Grain (10^{-2})	Scale	Cone	Seed	(Seed number/Cone)	Grain (10^{-2})	Scale
Furenai	102	145	3,793	7,519	1.434	(252)	569	6,085	10,302	3,084	(332)	929	7,218	11,033	3,503	(337)	1,039	7.530
Gamushi	5	215	3,431	11,424	2,404	(361)	666	9,020	13,994	3,214	(353)	910	10,780	15,680	4,321	(351)	1,231	11,359
Gamushi	103	180	3,287	10,231	2,036	(329)	619	8,195	11,689	3,157	(295)	1,070	8,532	13,604	3,476	(334)	1,041	10,128
Hiyama	9—①	118	2,869	6,487	1,060	(267)	397	5,427	10,345	2,554	(272)	939	7,791	12,296	3,144	(345)	911	9,152
Hiyama	9—②	125	2,714	8,436	1,689	(322)	525	6,747	9,004	2,206	(272)	811	6,798	11,092	2,627	(323)	813	8,465
Tomakomai	3—①	175	2,387	8,199	1,671	(323)	517	6,528	9,675	2,682	(270)	993	6,993	10,343	2,971	(309)	959	7,372
Tomakomai	3—②	120	2,564	4,364	940	(212)	443	3,424	6,067	1,264	(242)	522	4,803	7,259	1,779	(291)	610	5,480
Tomakomai	4	179	5,834	11,714	2,393	(338)	707	9,321	14,521	3,828	(366)	1,046	10,693	17,033	4,365	(357)	1,222	12,668
Average		157	3,360	8,547	1,703	(301)	556	6,843	10,700	2,749	(300)	903	7,951	12,292	3,273	(331)	979	9,019

Footnote: 1) Figures of cone, seed, grain or scale are average weights per cone, whole seed in a cone, grain of seed, or whole scale including axis in a cone, respectively.
2) Cones collected on May 6 are unpollinated strobili.

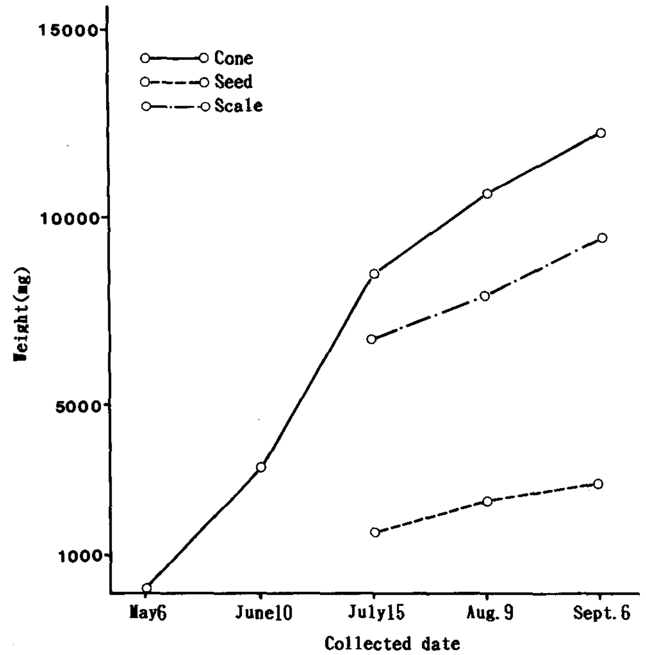

Fig. 2. Seasonal changes of average dry weight of cones from eight individual trees.
Note: Cones collected on May 6 are an unpollinated strobili.

The average weight of grain of the last collection was 9.79 mg, but this value included grains that were a little lighter than the previous ones, such as Gamushi 103, Hiyama 9—① and Tomakomai 3—①. However, this seemed to be a permissible error based on the calculation by seed number per cone and whole seed weight. Among individuals, the grain weight from Tomakomai 3—② was extremely light—as little as 6.10 mg—, equivalent to just half the weight of Tomakomai 4 (12.22 mg). The growth of the cone from Tomakomai 3—② was presumably obstructed as a result of an accident. Furthermore, it could be said that the development of cones from the same clone trees showed similar process to each other.

2. Seasonal changes in carbon and nitrogen contents

Seasonal changes in carbon and nitrogen contents are shown in Table 3.

Carbon···The carbon content in the cones of the first collection was 46.6% on the average with only a slight difference of 1.8 points between the maximum and minimum. On June 10, the content reached 49.0%, 2.4 points higher than the former, the low value of which was due to the fact that the cones of the first stage contained many minerals and nitrogen The average carbon content of the cones after the third collection progressed little by little from 53.0% to 54.0% in the last stage. Meanwhile, the content of the seeds gradually rose by 5.5% from 52.3% (July 15) to 57.8% (September 6), inferring that the seeds probably produced essential fat and oil of high carbon content through their growth. On the contrary, the content in the scale did not change in this manner.

Table 3. Seasonal changes in carbon and nitrogen contents of cones (%)

Collected date / Clone		May 6		June 10		July 15						Aug. 9						Sept. 6					
		Cone		Cone		Cone		Seed		Scale		Cone		Seed		Scale		Cone		Seed		Scale	
		C	N	C	N	C	N	C	N	C	N	C	N	C	N	C	N	C	N	C	N	C	N
Furenai	102	47.8	4.53	49.5	1.61	53.9	1.51	53.4	2.40	54.0	1.29	53.3	1.16	54.9	1.78	52.6	0.90	52.9	1.08	56.5	1.91	51.2	0.70
Gamushi	5	46.4	5.49	48.1	1.60	53.2	1.11	52.6	1.91	53.5	0.90	53.5	0.96	55.5	1.49	52.9	0.79	53.8	1.02	56.5	1.59	52.8	0.80
Gamushi	103	46.8	5.22	49.1	1.70	51.7	1.24	51.4	1.92	51.8	1.20	53.5	1.19	55.9	1.71	52.6	0.99	53.5	1.09	59.5	2.50	51.5	0.60
Hiyama	9—①	46.5	5.67	50.4	1.60	52.9	1.37	52.1	2.26	53.0	1.20	54.5	1.20	55.1	2.11	54.1	0.89	54.9	1.01	58.5	2.19	53.7	0.61
Hiyama	9—②	46.1	4.08	48.6	1.69	51.9	1.36	52.2	2.43	51.8	1.10	52.8	1.29	54.8	1.90	52.1	1.10	55.4	1.09	59.8	2.40	54.0	0.69
Tomakomai	3—①	46.0	4.29	47.9	2.01	54.1	1.22	52.7	2.09	54.5	1.00	53.6	1.05	54.5	1.71	53.2	0.80	53.7	1.07	56.9	1.98	52.4	0.71
Tomakomai	3—②	46.4	4.17	48.5	2.18	52.8	1.33	52.0	1.81	53.1	1.20	53.6	1.04	55.1	1.58	53.2	0.89	53.5	0.92	56.0	1.91	53.8	0.59
Tomakomai	4	47.0	4.41	50.0	1.70	53.4	1.28	52.3	2.00	53.7	1.09	52.3	1.21	54.7	1.80	51.5	1.00	54.1	1.21	58.9	2.11	52.5	0.89
Average		46.6	4.73	49.0	1.76	53.0	1.28	52.3	2.10	53.2	1.08	53.4	1.15	55.1	1.76	52.8	0.92	54.0	1.06	57.8	2.07	52.7	0.70

Table 4. Seasonal changes in nitrogen quantity per cone, seed, grain and scale (mg)

Collected date / Clone		May 6	June 10	July 15				Aug. 9				Sept. 6			
		Cone	Cone	Cone	Seed	Grain (10^{-2})	Scale	Cone	Seed	Grain (10^{-2})	Scale	Cone	Seed	Grain (10^{-2})	Scale
Furenai	102	7	61	113	34	13	79	120	55	17	65	120	67	20	53
Gamus i	5	12	55	136	46	13	90	134	48	14	86	160	69	20	91
Gamushi	103	9	56	137	39	12	98	139	54	18	85	148	87	26	61
Hiyama	9—①	7	46	89	24	9	65	124	54	20	70	124	69	20	55
Hiyama	9—②	5	46	115	41	13	74	117	42	15	75	122	63	20	59
Tomakomai	3—①	8	48	100	35	11	65	102	46	17	56	111	59	19	52
Tomakomai	3—②	5	56	58	17	8	41	63	20	8	43	67	34	12	33
Tomakomai	4	8	99	150	48	14	102	176	69	19	107	206	92	26	114
Average		8	58	112	36	12	77	122	49	16	73	133	68	20	65

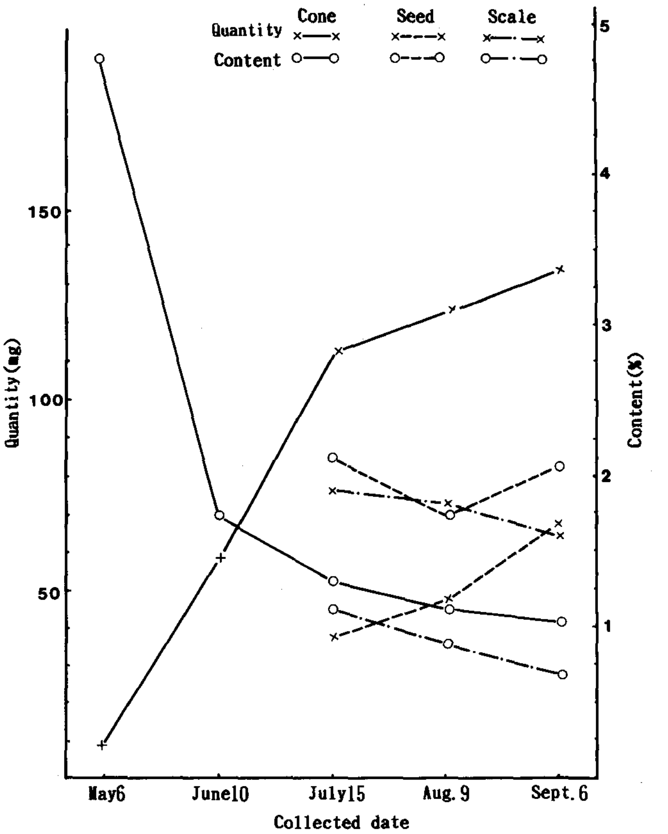

Fig. 3. Seasonal changes in average nitrogen content in cones from eight individual trees (quantity per cone, whole seed and scale).

Nitrogen···Seasonal changes in nitrogen content were noticeable. As shown also in Fig. 3, the average nitrogen content was 4.73% in the cones collected on May 6, but sharply decreased to 1.76% at the second collection, and to 1.06% at the last collection. Meanwhile, the average content in seed increased at about 2%, with a slightly high content both in the third and last collections. The nitrogen quantity per cone, seed, grain, and scale is shown in Table 4 and in Fig. 3. The average quantity per cone was 8 mg at the first collection and rose to 58 mg at the second collection, or about 7 times, and to 112 mg at the third collection, but subsequently the change was not so great. The quantity per seed increased from 36 mg on July 15 to 68 mg on September 6. The proportions of the average nitrogen quantity in seed to that in cone rose to 32%, 40%, and 51% in the cones collected on July 15, August 9, and September 6, respectively, while the proportions of that in scale decreased toward the last collection. This fact indicated that the nitrogen in the cone was being transferred from scale to seed and that protein and amino acid, the most important substances for germination, were produced and deposited in the seed. Accordingly, the quantity of nitrogen per grain increased naturally from 0.12 mg to 0.20 mg through the growth of cones. The range of the quantity per grain in the last stage was between 0.12 mg of Tomakomai 3—② and 0.26 mg of Gamushi 103 and Tomakomai 4, and the value of the former was extremely low among individuals.

3. Seasonal changes in mineral content

Seasonal changes in mineral content are shown in Table 5 and Fig. 4. The mineral content in the cones at the first collection was as high as 6.6% on the average, and sharply dropped to the half that value, 3.4%, at the second collection. However, the quantity per cone remarkably increased from 11 mg to 115 mg, ten times the former. Afterward, the percentages of mineral in cone hardly changed, while the quantity in cone strikingly increased toward the last stage. The average mineral content in seed also hardly changed, ranging from 2.1% to 2.3% in the course of growth, as well as in scale ranging from 2.6% to 2.9%. The average quantity in seed, however, increased from 38 mg at the third collection to 74 mg at the last collection. The proportions of seed mineral to cone mineral also gradually increased, from 18% (July 15), to 20% (August 9) to 22% (September 6). The average mineral quantity in scale varied from 176 mg at the third collection, equivalent to 4.7 times as much as that in seed, to 259 mg of the last collection, equivalent to 3.5 times that in seed.

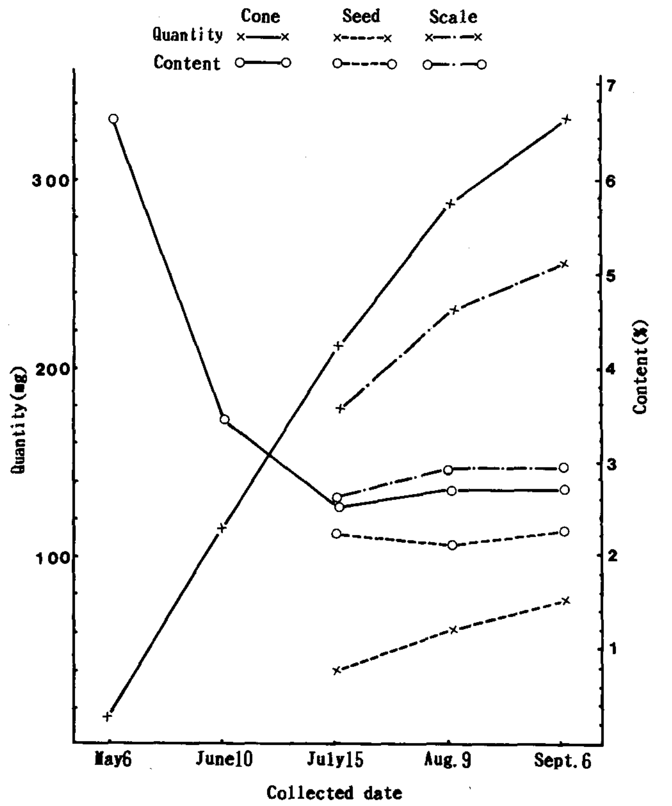

Fig. 4. Seasonal changes in average mineral content in cones from eight individual trees.

4. Seasonal changes in phosphorus, potassium, magnesium, and calcium contents

Phosphorus ··· Seasonal changes in phosphorus content as oxide in the mineral of cones are shown in Fig. 5, together with other inorganic components. The phosphorus content in minerals of the cone at the first collection was 25.3%, but sharply decreased to 14.1% at the second collection, and afterward it followed the similar percentages to the last collection with a little increment. Meanwhile, the content in minerals of seed gradually rose from 20.7% to 22.3% and 28.1% at the last collection, while that of scale was about 15%.

Seasonal changes in phosphorus content as oxide are shown in Table 6. The average content in the cones collected on May 6 was 1.72%, ranging from 1.34% of Hiyama 9—② to 2.12% of Gamushi 5. In the second collection, it dropped to 0.49% and subsequently remained almost steady to the last collection. However, the average quantity per cone rose remarkably from 2.7 mg at the first collection to 16.4 mg at the second collection, or 6 times more. It gradually increased 62.0 mg at the last collection. Meanwhile, the quantity in seed at the third collection was 7.8 mg and increased to 20.0 mg at the last one, along with the similar process of that in scale from 27.3 mg at the third collection to 42.0 mg at the last one. The proportion of the average phosphorus quantity in seed to that in cone gradually increased from 22% to 27% and 32%. The average quantity per grain also increased from 0.026 mg to 0.060 mg at the last collection.

Potassium ··· As shown in Fig. 5, potassium content in the mineral was the

Table 5. Seasonal changes in mineral content of cones

Collected date	May 6		June 10		July 15						
	Cone		Cone		Cone		Seed		Grain	Scale	
Clone	%	mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg
Furenai 102	7.2	11	3.0	112	2.8	214	2.1	30	118	3.0	184
Gamushi 5	6.8	15	3.4	118	2.0	232	1.5	36	100	2.2	196
Gamushi 103	6.1	11	3.0	98	2.2	229	1.9	38	114	2.3	191
Hiyama 9—①	6.9	8	3.4	97	2.6	169	2.6	30	110	2.6	139
Hiyama 9—②	6.0	8	3.0	81	2.5	213	2.9	49	152	2.4	164
Tomakomai 3—①	6.4	11	3.8	90	2.6	209	2.5	43	133	2.6	166
Tomakomai 3—②	6.3	8	4.1	106	2.6	112	1.5	14	66	2.8	98
Tomakomai 4	7.0	13	3.8	219	2.8	332	2.7	64	188	2.9	268
Average	6.6	11	3.4	115	2.5	214	2.2	38	123	2.6	176

Collected date	Aug. 9							Sept. 6						
	Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale	
Clone	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg
Furenai 102	2.9	301	1.9	60	180	3.3	241	3.1	340	2.3	80	236	3.5	260
Gamushi 5	2.2	312	1.7	54	153	2.4	258	2.2	350	1.8	77	217	2.4	273
Gamushi 103	2.4	280	1.9	59	198	2.6	221	2.5	337	2.5	85	254	2.5	252
Hiyama 9—①	3.0	307	2.5	65	239	3.1	242	2.8	341	2.6	82	237	2.8	259
Hiyama 9—②	2.7	242	2.6	57	208	2.7	185	2.9	322	2.8	72	224	3.0	252
Tomakomai 3—①	2.9	282	2.0	53	197	3.3	229	2.8	294	2.1	64	205	3.1	230
Tomakomai 3—②	2.8	167	2.1	26	106	3.0	141	2.6	190	1.8	32	109	2.9	158
Tomakomai 4	2.9	414	2.2	84	229	3.1	330	2.9	489	2.4	104	292	3.0	385
Average	2.7	288	2.1	57	189	2.9	231	2.7	333	2.3	74	222	2.9	259

Table 6. Seasonal changes in phosphorus content as oxide of cones

Collected date	May 6		June 10		July 15							Aug. 9							Sept. 6						
	Cone		Cone		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale	
Clone	%	mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg
Furenai 102	1.80	2.7	0.48	18.2	0.46	34.6	0.50	7.2	28	0.45	27.4	0.52	53.7	0.43	13.3	40	0.56	40.4	0.61	67.7	0.60	21.0	62	0.62	46.7
Gamushi 5	2.12	4.6	0.53	18.2	0.42	49.2	0.32	7.7	21	0.46	41.5	0.49	69.0	0.47	15.1	43	0.50	53.9	0.51	80.2	0.60	25.9	74	0.48	54.3
Gamushi 103	1.41	2.5	0.47	15.4	0.37	37.6	0.32	6.5	20	0.38	31.1	0.46	53.7	0.46	14.5	49	0.46	39.2	0.45	60.7	0.58	20.2	60	0.40	40.5
Hiyama 9—①	1.49	1.8	0.47	13.5	0.36	23.5	0.58	6.1	23	0.32	17.4	0.37	38.2	0.52	13.3	49	0.32	24.9	0.44	53.7	0.66	20.8	60	0.36	32.9
Hiyama 9—②	1.34	1.7	0.44	11.9	0.42	35.5	0.46	7.8	24	0.41	27.7	0.46	41.6	0.58	12.8	47	0.42	28.8	0.54	60.4	0.72	18.9	58	0.49	41.5
Tomakomai 3—①	1.91	3.3	0.48	11.5	0.34	28.0	0.58	9.7	30	0.28	18.3	0.33	31.8	0.43	11.5	43	0.29	20.3	0.54	55.5	0.53	15.7	51	0.54	39.8
Tomakomai 3—②	1.43	1.7	0.49	12.6	0.36	15.9	0.34	3.2	15	0.37	12.7	0.49	29.6	0.44	5.6	23	0.50	24.0	0.53	38.7	0.51	9.1	31	0.54	29.6
Tomakomai 4	1.96	3.5	0.51	29.8	0.48	56.2	0.60	14.3	42	0.45	41.9	0.42	61.0	0.42	16.1	44	0.42	44.9	0.46	79.1	0.65	28.4	79	0.40	50.7
Average	1.72	2.7	0.49	16.4	0.41	35.1	0.45	7.8	26	0.40	27.3	0.44	47.3	0.46	12.8	42	0.43	34.5	0.51	62.0	0.61	20.0	60	0.48	42.0

Table 7. Seasonal changes in potassium content as oxide of cones

Collected date	May 6		June 10		July 15							Aug. 9							Sept. 6						
	Cone		Cone		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale	
Clone	%	mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg
Furenai 102	2.34	3.5	0.96	36.4	0.91	68.1	0.63	8.5	34	0.98	59.6	1.16	119.8	0.56	17.3	52	1.42	102.5	1.18	130.5	0.76	26.5	79	1.38	103.9
Gamushi 5	2.17	4.7	1.32	45.3	0.75	86.1	0.53	13.0	36	0.81	73.1	0.86	120.3	0.52	16.8	48	0.96	103.5	0.87	135.9	0.49	21.2	60	1.01	114.7
Gamushi 103	2.30	4.1	1.04	34.2	0.74	76.1	0.64	13.0	39	0.77	63.1	0.92	107.8	0.61	19.1	65	1.04	88.7	0.88	120.0	0.77	26.8	80	0.92	93.2
Hiyama 9—①	2.87	3.4	1.26	36.1	0.93	60.3	0.82	8.7	32	0.95	51.6	1.00	102.9	0.80	20.3	67	1.06	82.6	0.94	115.9	0.72	22.6	66	1.02	93.3
Hiyama 9—②	2.54	3.2	1.00	27.1	0.96	80.7	0.94	15.9	49	0.96	64.8	1.00	90.3	0.83	18.3	67	1.06	72.0	1.09	121.2	0.86	22.6	70	1.17	98.6
Tomakomai 3—①	1.98	3.5	1.35	32.2	0.81	66.5	0.78	13.0	40	0.82	53.5	1.06	102.9	0.63	16.9	63	1.23	86.0	1.03	106.3	0.67	19.9	64	1.17	86.4
Tomakomai 3—②	2.61	3.1	1.36	34.9	0.89	38.9	0.50	4.7	22	1.00	34.2	1.08	65.4	0.65	8.2	34	1.19	57.2	1.06	77.1	0.58	10.3	35	1.22	66.8
Tomakomai 4	3.01	5.4	1.32	77.0	0.95	111.2	0.87	20.8	61	0.97	90.4	1.14	164.9	0.66	25.3	69	1.31	139.6	1.08	184.0	0.79	34.5	96	1.18	149.5
Average	2.48	3.9	1.20	40.4	0.87	73.5	0.71	12.2	39	0.91	61.3	1.03	109.3	0.66	17.8	58	1.16	91.5	1.02	123.8	0.71	23.0	69	1.13	100.8

highest of all inorganic components examined, and the content was nearly constant from 35% to 37% in minerals of cone, throughout growth. The quantity of potassium in seed was rather less than that in scale, in which the maximum was about 40% in the cones collected on September 9. Seasonal changes in potassium as oxide are shown in Table 7. The potassium content of the cones at the first collection was 2.48% on the

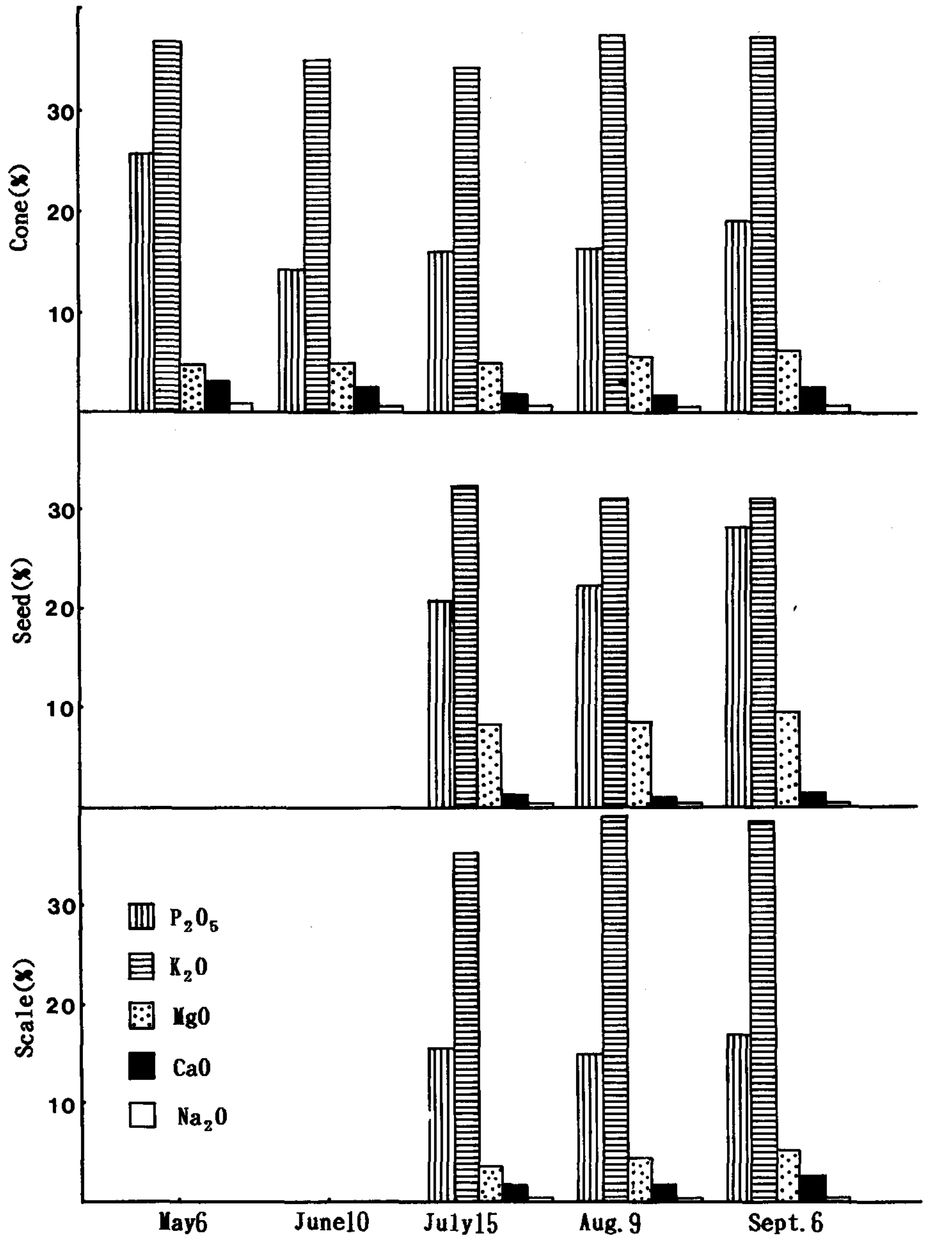

Fig. 5. Seasonal changes in average contents of chemical components in the mineral of cones from eight individual trees.

Table 8. Seasonal changes in magnesium content as oxide of cones

Collected date	May 6		June 10		July 15							Aug. 9							Sept. 6						
	Cone		Cone		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale	
Clone	%	mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg	%	mg	%	mg	10^{-3}mg	%	mg
Furenai 102	0.29	0.4	0.18	6.8	0.11	8.0	0.13	1.9	8	0.10	6.1	0.14	14.0	0.15	4.6	14	0.13	9.4	0.18	20.2	0.22	7.7	23	0.17	12.5
Gamushi 5	0.35	0.7	0.14	4.8	0.11	12.1	0.13	3.1	9	0.10	9.0	0.14	19.1	0.16	5.1	15	0.13	14.0	0.15	22.9	0.17	7.3	21	0.14	15.6
Gamushi 103	0.26	0.5	0.12	3.9	0.10	9.8	0.12	2.4	7	0.09	7.4	0.13	14.9	0.15	4.7	16	0.12	10.2	0.14	18.8	0.24	8.3	25	0.10	10.5
Hiyama 9–①	0.28	0.3	0.17	4.9	0.13	8.3	0.27	2.9	11	0.10	5.4	0.15	15.2	0.23	5.8	21	0.12	9.4	0.19	23.9	0.22	6.9	20	0.19	17.0
Hiyama 9–②	0.24	0.3	0.15	4.1	0.11	9.1	0.26	4.4	14	0.07	4.7	0.18	16.0	0.23	5.1	19	0.16	10.9	0.18	20.0	0.31	8.1	25	0.14	11.9
Tomakomai 3–①	0.32	0.6	0.15	3.6	0.11	8.9	0.22	3.7	11	0.08	5.2	0.11	10.6	0.16	4.3	16	0.09	6.3	0.16	16.7	0.23	6.8	22	0.14	9.9
Tomakomai 3–②	0.26	0.3	0.16	4.0	0.09	3.9	0.10	0.9	4	0.09	3.0	0.15	8.6	0.17	2.1	9	0.14	6.5	0.15	10.9	0.15	2.7	9	0.15	8.2
Tomakomai 4	0.32	0.6	0.17	9.9	0.13	15.5	0.26	6.2	16	0.10	9.3	0.15	21.5	0.17	6.5	18	0.14	15.0	0.18	31.0	0.20	8.7	24	0.18	22.3
Average	0.29	0.5	0.16	5.3	0.11	9.5	0.19	3.2	10	0.09	6.3	0.14	15.0	0.18	4.8	16	0.13	10.2	0.17	20.6	0.22	7.1	21	0.15	13.5

Table 9. Seasonal changes in calcium content as oxide of cones

Collected date	May 6		June 10		July 15							Aug. 9							Sept. 6						
	Cone		Cone		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale		Cone		Seed		Grain	Scale	
Clone	%	mg	%	mg	%	mg	%	mg	10^{-4}mg	%	mg	%	mg	%	mg	10^{-4}mg	%	mg	%	mg	%	mg	10^{-4}mg	%	mg
Furenai 102	0.30	0.4	0.08	3.0	0.04	3.1	0.02	0.2	8	0.05	2.9	0.03	3.5	0.02	0.6	18	0.04	2.9	0.09	10.2	0.03	1.1	33	0.12	9.1
Gamushi 5	0.23	0.5	0.06	2.1	0.04	4.4	0.01	0.3	8	0.05	4.1	0.05	6.6	0.02	0.5	14	0.06	6.1	0.05	7.6	0.02	0.8	23	0.06	6.8
Gamushi 103	0.16	0.3	0.10	3.3	0.03	2.6	0.02	0.3	9	0.03	2.3	0.04	4.2	0.02	0.6	20	0.04	3.6	0.07	8.8	0.03	1.0	30	0.08	7.8
Hiyama 9–①	0.13	0.2	0.07	2.0	0.04	2.8	0.03	0.3	11	0.05	2.5	0.05	5.3	0.02	0.5	17	0.06	4.8	0.07	8.3	0.03	0.8	23	0.08	7.5
Hiyama 9–②	0.14	0.2	0.06	1.6	0.04	3.1	0.02	0.3	9	0.04	2.8	0.04	3.4	0.02	0.4	15	0.04	3.0	0.07	7.8	0.04	1.1	34	0.08	6.7
Tomakomai 3–①	0.26	0.5	0.07	1.7	0.04	2.9	0.03	0.4	12	0.04	2.5	0.04	3.8	0.02	0.4	15	0.05	3.4	0.05	5.1	0.02	0.6	19	0.06	4.4
Tomakomai 3–②	0.15	0.2	0.05	1.3	0.04	1.8	0.02	0.2	9	0.05	1.6	0.04	2.3	0.01	0.2	9	0.05	2.1	0.06	4.2	0.02	0.4	14	0.07	3.8
Tomakomai 4	0.14	0.3	0.06	3.5	0.05	5.7	0.03	0.6	18	0.06	5.1	0.04	5.9	0.02	0.7	19	0.05	5.2	0.06	9.8	0.02	0.7	20	0.07	9.1
Average	0.19	0.3	0.07	2.3	0.04	3.3	0.02	0.3	11	0.05	3.0	0.04	4.4	0.02	0.5	16	0.05	3.9	0.07	7.7	0.03	0.8	25	0.08	6.9

average, ranging between 1.98% and 3.01%, while the average quantity per cone was 3. 9 mg. At the second collection, it dropped to 1.20%, less than half the value of the first collection, while the quantity rose to 40.4 mg, over ten times that of the former. Subsequently, the content per cone hardly varied—only 0.87%, 1.03%, and 1.02% at the three collections, respectively—through the growth of cones. However, the quantity of phosphorus in cones rose from 73.5 mg at the third collection to 109.3 mg and 123.8 mg at maturity, in proportion to the increase of cone weight. The phosphorus content in seed was nearly constant from the third collection to the last collection. The quantity in seed from mature cones was 23.0 mg on the average, ranging between 10.3 mg for Tomakomai 3—② and 34.5 mg for Tomakomai 4. The proportion of the average quantity in seed to that in cone was as low as 16% to 18%. This indicated that the phosphorus content in cones was chiefly based on the quantity in scale.

Magnesium···As shown in Fig. 5, the magnesium content in minerals of cone increased only 4.4% to 6.0% in the course of growth. The content in the mineral of seed (8.2% to 9.5%) was about twice that of scale (3.6% to 5.1%), so that it was inferred that the seed would require much magnesium presumably for its germination.

Seasonal changes in magnesium content as oxide are shown in Table 8. The magnesium content in the cones at the first collection was 0.29% on the average, while that at the last collection was 0.17%. The average quantity in cones varied from 0.5 mg at the first collection to 20.6 mg at the last collection. The proportion of the average quantity per seed to that per cone was nearly constant at about 34% through the cone growth. The magnesium quantity per grain from the cones at the last collection was 0.021 mg on the average, in which only the grain of Tomakomai 3—② contained an extremely small quantity, 0.009 mg, compared with that of other trees.

Calcium···As shown in Fig. 5, the calcium content in the mineral of cone was unexpectedly low, compared with magnsium. The content was about 2%, with a little increment of that in matured cones. The content in the mineral of seed was very low, about 1%, while that of scale 2% or so.

Seasonal changes in calcium content as oxide are shown in Table 9. The average content in the cones collected on May 6, was 0.19%, but dropped to 0.07% at the second collection, and 0.04% at the third collection. Subsequently, the content varied only 0.04% to 0.07%. The quantity of calcium in seed from mature cones was 0.8 mg, and

Table 10. Chemical composition in the mineral of cones from *Abies sachalinensis** (%)

Sample	Collected date	Mineral content	Chemical components as oxide in mineral								
			P_2O_5	K_2O	MgO	CaO	Na_2O	SiO_2	Al_2O_3	Fe_2O_3	Total
Cone	June 18	3.20	23.1	44.3	6.0	3.8	0.3	17.8	3.2	1.4	99.9
Cone	July 12	2.93	15.7	42.6	5.1	3.4	0.7	17.7	4.0	4.3	93.5
Cone	Sept. 22	2.84	17.9	41.6	9.5	4.6	0.9	12.0	1.5	4.0	92.0
Seed	Sept. 22	1.97	31.0	36.1	9.1	4.1	0.7	5.8	3.6	1.6	92.0

* A 45-year-old planted tree having 14.0 m high and 32 cm in DBH, located in the Nayoro Prefectural Forest.

the proportion of the average calcium quantity per seed to that per cone was calculated at only 10%, which inferred that calcium was not so important in the germination of seed. Accordingly, the quantity per grain of the seed from mature cones was only 0.0025 mg on the average.

As shown in Fig. 5, sodium content in the mineral was much less than calcium, so that it could be neglected. The rest of inorganic components were presumably such substances as silicon, aluminum, and iron, as shown in Table 10 (previously examined by one of the authors), in which the total amounts covered more than 90% of minerals[9].

5. Contents of chemical components in mature cones.

The contents of chemical components in seed and scale from mature cones are shown in Table 11. The average carbon content in seed was 57.7%, which was higher than in scale by 4.6 points. The average nitrogen content was 1.8% in the former which was relatively high, equivalent to just three times the latter. Meanwhile, the total mineral content in seed was 1.9%, a little lower than that in scale, but the average contents of phosphorus and magnesium in seed were higher than those in scale, while the contents of potassium and calcium in the former were lower than those in the latter. From this fact, it was inferred that the substances necessary for germination were much present in the seed. Among eleven clones, the seeds of the same clone showed generally similar contents of chemical components.

The weights and quantities of chemical components per cone and seed in mature cones are shown in Table 12. The average cone weight was 12.22 g, in which the seed was 3.00 g on the average, about 25% of cone. The carbon quantity per cone was 6.62 g, equivalent to 54% of cone weight, and the nitrogen and mineral quantities were 106 mg (0.9%) and 284 mg (2.3%), respectively. The highest in minerals of cone was potassium, 104 mg on the average, followed by phosphorus with 41 mg and magnesium with 16 mg. Meanwhile, the average carbon quantity in seed was 1.73 g or 26% of that in cones, and the nitrogen quantity was 55 mg or 55% of that in cones.

6. Quantities of chemical components per grain and germination rate of mature seeds

As shown in Table 13, the average seed number per cone was 314 grains, ranging from 242 to 370 grains at only 9.2% of the coefficient of variation. The average weight of grain was 9.49 mg, ranging from 6.10 to 13.35 mg. The quantities of carbon and nitrogen per grain were 5.48 mg and 0.17 mg, respectively, and the coefficients of variation were higher in the latter than the former. The quantity of total minerals was 0.18 mg, showing a similar value to that of nitrogen. The maximum quantity in minerals was potassium, followed by phosphorus and magnesium. The average germination rate was 29.1%, ranging from 0%, non-germination, to 51.1%, so that the coefficient of variation was as high as 48.6%, Among eleven clones, the grains of seed from Gamushi 5 and Tomakomai 4 were generally heavy, substantial, and rich in nutrient substances, while those from Gamushi 102 and Tomakomai 3 were light and poor in nutrients. Accordingly, the former were higher in the germination rate than the latter. Furthermore, it was shown that the germination rate of the seed from the Hiyama 9 clone was

Table 11. Contents of chemical components in seed and scale from mature cones (%)

Clone		Individual No. (Site No.)	Seed							Scale						
			Carbon	Nitrogen	Mineral	P_2O_5	K_2O	MgO	CaO	Carbon	Nitrogen	Mineral	P_2O_5	K_2O	MgO	CaO
Furenai	102	108	56.5	1.9	2.3	0.60	0.76	0.22	0.03	51.2	0.7	3.5	0.62	1.38	0.17	0.12
Furenai	102	315	56.8	1.7	1.8	0.42	0.58	0.14	0.02	52.9	0.5	2.6	0.39	1.01	0.14	0.07
Furenai	102	(5)	58.2	1.6	1.8	0.36	0.62	0.16	0.03	53.4	0.5	2.3	0.15	0.81	0.07	0.02
Furenai	102	508	56.5	1.2	1.3	0.30	0.43	0.08	0.03	51.6	0.6	2.3	0.40	0.92	0.15	0.08
Gamushi	5	240	56.5	1.6	1.8	0.60	0.49	0.17	0.02	52.8	0.8	2.4	0.48	1.01	0.14	0.06
Gamushi	5	540	55.5	1.3	1.4	0.33	0.52	0.12	0.02	52.4	0.5	2.2	0.38	0.91	0.10	0.09
Gamushi	5	622	55.9	1.2	1.3	0.29	0.42	0.10	0.02	54.0	0.5	2.2	0.35	0.84	0.10	0.06
Gamushi	5	259	58.1	1.6	1.8	0.47	0.56	0.17	0.03	52.4	0.7	2.4	0.38	0.91	0.11	0.10
Gamushi	6	(4)	55.7	0.8	1.1	0.28	0.43	0.08	0.03	52.4	0.5	2.0	0.25	0.74	0.08	0.05
Gamushi	6	(5)	56.2	0.9	1.1	0.27	0.36	0.08	0.02	53.4	0.6	1.9	0.35	0.82	0.11	0.04
Gamushi	102	(4)	57.2	1.5	1.7	0.40	0.60	0.14	0.03	52.2	0.5	2.7	0.31	0.99	0.13	0.10
Gamushi	102	150	54.7	0.8	1.0	0.22	0.37	0.07	0.02	53.3	0.7	2.4	0.46	0.95	0.13	0.08
Gamushi	103	387	59.5	2.5	2.5	0.58	0.77	0.24	0.03	51.5	0.6	2.5	0.40	0.92	0.10	0.08
Gamushi	103	(4)	57.4	1.5	1.5	0.33	0.49	0.13	0.03	53.8	0.6	2.0	0.25	0.71	0.10	0.09
Gamushi	104	(4)	55.4	1.3	1.5	0.30	0.50	0.11	0.02	53.9	0.6	1.8	0.16	0.68	0.11	0.07
Gamushi	104	(5)	58.4	1.9	2.2	0.47	0.70	0.18	0.02	54.6	0.5	2.3	0.13	1.02	0.09	0.07
Gamushi	108	(4)	56.2	1.7	1.6	0.32	0.52	0.11	0.02	54.0	0.6	2.0	0.18	0.71	0.10	0.04
Gamushi	108	(5)	60.8	1.9	2.2	0.41	0.71	0.20	0.02	52.9	0.5	3.0	0.32	1.11	0.19	0.12
Hiyama	9	570	58.5	2.2	2.6	0.66	0.72	0.22	0.03	53.7	0.6	2.8	0.36	1.02	0.19	0.08
Hiyama	9	639	59.8	2.4	2.8	0.72	0.86	0.31	0.04	54.0	0.7	3.0	0.49	1.17	0.14	0.08
Hiyama	9	183	57.6	2.2	2.2	0.67	0.70	0.17	0.03	51.5	0.4	2.5	0.31	1.00	0.10	0.07
Hiyama	9	18	59.4	2.2	2.3	0.39	0.74	0.18	0.02	51.1	0.3	2.7	0.31	0.95	0.16	0.08
Hiyama	9	196	58.6	2.1	2.2	0.47	0.67	0.16	0.02	55.0	0.3	3.1	0.29	1.07	0.23	0.15
Hiyama	9	165	60.9	2.1	2.4	0.53	0.77	0.20	0.02	52.9	0.4	2.9	0.39	1.04	0.22	0.14
Shiraoi	2	(4)	58.7	1.7	1.8	0.38	0.58	0.15	0.03	53.4	0.4	2.5	0.18	0.94	0.12	0.11
Shiraoi	2	1	59.8	2.1	2.1	0.35	0.68	0.15	0.03	53.9	0.4	2.1	0.10	0.69	0.06	0.04
Shiraoi	2	2	58.7	2.0	1.8	0.51	0.55	0.17	0.03	54.4	0.5	2.3	0.17	0.87	0.12	0.07
Tomakomai	3	15	56.9	2.0	2.1	0.53	0.67	0.23	0.02	52.4	0.7	3.1	0.54	1.17	0.14	0.06
Tomakomai	3	582	56.0	1.9	1.8	0.51	0.58	0.15	0.02	53.8	0.6	2.9	0.54	1.22	0.15	0.07
Tomakomai	3	362	57.4	1.9	2.0	0.35	0.68	0.15	0.02	54.3	0.6	2.4	0.28	0.86	0.11	0.11
Tomakomai	3	515	57.3	1.9	1.7	0.33	0.58	0.14	0.02	53.8	0.6	2.3	0.29	0.88	0.10	0.06
Tomakomai	3	154	56.9	1.5	1.8	0.38	0.62	0.15	0.02	52.8	0.5	2.9	0.17	1.00	0.12	0.05
Tomakomai	4	95	58.9	2.1	2.4	0.65	0.79	0.20	0.02	52.5	0.9	3.0	0.40	1.18	0.18	0.07
Tomakomai	4	296	58.5	2.6	2.1	0.36	0.63	0.15	0.02	52.8	0.4	2.4	0.16	0.79	0.07	0.02
Tomakomai	4	447	57.9	2.2	2.3	0.38	0.72	0.17	0.02	52.8	0.4	2.6	0.15	0.89	0.08	0.05
Tomakomai	4	321	58.5	2.3	2.1	0.36	0.69	0.16	0.03	53.2	0.5	2.7	0.30	1.10	0.11	0.09
Average			57.7	1.8	1.9	0.43	0.61	0.16	0.02	53.1	0.6	2.5	0.30	0.95	0.12	0.08

Table 12. Weights and quantities of chemical components per cone and seed in mature cones

Clone		Individual No. (Site No.)	Cone								Seed								
			Weight g	Carbon g	Nitrogen mg	Mineral mg	P_2O_5 mg	K_2O mg	MgO mg	CaO mg	Weight g	Seed wt. /Cone wt. %	Carbon g	Nitrogen mg	Mineral mg	P_2O_5 mg	K_2O mg	MgO mg	CaO mg
Furenai	102	108	11.03	5.83	120	340	68	130	20	10	3.50	31.8	1.98	67	80	21	27	8	1.1
Furenai	102	315	9.03	4.88	77	211	36	80	13	5	2.64	29.2	1.50	45	47	11	15	4	0.6
Furenai	102	(5)	10.23	5.60	83	224	21	77	10	2	2.89	28.2	1.68	46	53	10	18	5	0.5
Furenai	102	508	12.62	6.63	91	264	47	104	17	9	2.50	19.8	1.41	30	32	7	11	2	0.7
Gamushi	5	240	15.68	8.44	160	350	78	136	21	6	4.32	27.6	2.44	69	77	26	21	7	0.8
Gamushi	5	540	12.16	6.48	87	246	45	98	13	9	3.26	26.8	1.81	42	46	11	17	4	0.8
Gamushi	5	622	14.12	7.69	96	277	48	103	14	7	3.64	25.8	2.04	44	46	11	15	4	0.7
Gamushi	5	259	12.15	6.55	114	267	49	99	15	10	3.28	27.0	1.91	52	59	15	18	6	1.0
Gamushi	6	(4)	18.07	9.55	98	334	46	126	14	9	2.61	14.5	1.45	21	29	7	11	2	0.8
Gamushi	6	(5)	10.05	5.42	67	173	34	73	10	4	2.11	21.0	1.19	19	23	6	8	2	0.4
Gamushi	102	(4)	7.15	3.82	52	179	24	64	10	6	1.67	23.4	0.96	25	29	7	10	2	0.4
Gamushi	102	150	12.45	6.66	89	266	52	106	15	9	2.04	16.4	1.11	16	21	4	8	1	0.6
Gamushi	103	387	13.60	7.28	148	337	61	120	19	9	3.48	25.6	2.07	87	85	20	27	8	1.0
Gamushi	103	(4)	11.14	6.08	88	208	30	74	12	8	2.43	21.8	1.39	36	36	8	12	3	0.7
Gamushi	104	(4)	17.83	9.65	126	316	32	116	20	11	2.80	15.7	1.55	36	42	8	14	3	0.6
Gamushi	104	(5)	11.59	6.46	107	265	27	107	14	7	3.52	30.4	2.06	67	77	17	25	6	0.8
Gamushi	108	(4)	20.26	11.01	157	389	41	138	21	7	3.23	16.0	1.82	55	50	10	17	4	0.7
Gamushi	108	(5)	8.87	4.90	81	244	31	88	17	8	2.61	29.4	1.58	50	58	11	19	5	0.6
Hiyama	9	570	12.30	6.75	124	341	54	116	24	8	3.14	25.6	1.84	69	82	21	23	7	0.8
Hiyama	9	639	11.09	6.14	122	325	60	121	20	8	2.63	23.7	1.57	63	72	19	23	8	1.2
Hiyama	9	183	10.53	5.59	86	251	42	97	12	7	2.72	25.8	1.57	60	59	18	19	5	0.9
Hiyama	9	18	11.06	5.88	86	288	37	99	18	7	2.79	25.2	1.65	61	65	11	21	5	0.4
Hiyama	9	196	10.41	5.83	82	298	35	100	22	12	2.81	27.0	1.65	59	61	13	19	5	0.7
Hiyama	9	165	9.39	5.16	79	259	40	91	20	11	2.43	25.8	1.48	51	58	13	19	5	0.7
Shiraoi	2	(4)	10.04	5.52	80	230	25	83	13	9	3.07	30.6	1.80	52	56	12	18	5	1.0
Shiraoi	2	1	13.46	7.42	102	279	21	93	10	5	2.79	20.8	1.67	59	57	10	19	4	0.8
Shiraoi	2	2	12.96	7.22	122	276	35	100	18	8	3.87	29.9	2.27	77	71	20	21	7	1.3
Tomakomai	3	15	10.34	5.55	111	286	56	100	17	5	2.97	28.7	1.69	59	64	16	20	7	0.6
Tomakomai	3	582	7.26	3.94	67	190	39	77	11	4	1.78	24.5	1.00	34	32	9	10	3	0.4
Tomakomai	3	362	8.70	4.79	81	199	26	71	11	7	2.28	26.2	1.31	43	46	8	16	3	0.5
Tomakomai	3	515	8.83	4.84	85	191	26	70	10	4	2.49	28.1	1.42	47	43	8	14	4	0.4
Tomakomai	3	154	10.38	5.61	83	266	24	92	13	4	3.11	30.0	1.77	47	55	12	19	5	0.7
Tomakomai	4	95	17.03	9.22	206	489	79	184	31	10	4.37	25.6	2.57	92	104	28	35	9	0.7
Tomakomai	4	296	16.36	8.88	158	384	34	117	13	3	4.20	25.7	2.46	109	88	15	21	5	0.7
Tomakomai	4	447	17.10	9.26	149	426	36	145	18	7	4.49	26.2	2.60	99	103	17	32	8	0.6
Tomakomai	4	321	14.50	7.90	137	365	46	145	18	10	3.54	24.4	2.07	82	73	13	25	6	0.7
Average			12.22	6.62	106	284	41	104	16	7	3.00	25.1	1.73	55	58	13	18	5	0.7

Table 13. Weights and quantities of chemical components per grain of seed from mature cones, and germination rate of seed

Clone		Individual No. (Site No.)	Seed number /Cone	Weight mg	Carbon mg	Nitrogen mg	Mineral mg	P_2O_5 10^{-3}mg	K_2O 10^{-3}mg	MgO 10^{-3}mg	CaO 10^{-3}mg	Germination rate %
Furenai	102	108	337	10.39	5.87	0.20	0.24	62	79	23	3.3	34.0
Furenai	102	315	309	8.54	4.85	0.15	0.15	36	50	12	1.8	*
Furenai	102	(5)	297	9.74	5.67	0.16	0.18	35	60	16	1.6	38.6
Furenai	102	508	321	7.80	4.41	0.09	0.10	23	34	6	2.2	5.9
Gamushi	5	240	351	12.30	6.95	0.20	0.22	74	60	21	2.3	29.2
Gamushi	5	540	304	10.69	5.93	0.14	0.15	35	56	13	2.6	37.6
Gamushi	5	622	331	11.02	6.16	0.13	0.14	32	46	11	2.0	24.0
Gamushi	5	259	314	10.46	6.08	0.17	0.19	49	59	18	3.2	21.7
Gamushi	6	(4)	251	10.42	5.80	0.08	0.12	29	45	8	3.2	20.3
Gamushi	6	(5)	322	6.54	3.68	0.06	0.07	18	24	5	1.2	9.5
Gamushi	102	(4)	242	6.93	3.96	0.10	0.12	28	42	10	1.8	0.0
Gamushi	102	150	299	6.80	3.72	0.05	0.07	15	25	5	2.0	4.9
Gamushi	103	387	334	10.38	6.17	0.26	0.25	60	80	25	3.0	28.4
Gamushi	103	(4)	300	8.11	4.66	0.12	0.12	27	40	11	2.3	20.0
Gamushi	104	(4)	293	9.57	5.30	0.12	0.14	29	48	11	2.0	29.3
Gamushi	104	(5)	338	10.44	6.10	0.20	0.23	49	73	19	2.5	34.1
Gamushi	108	(4)	320	10.11	5.68	0.17	0.16	32	53	11	2.2	20.1
Gamushi	108	(5)	296	8.81	5.36	0.17	0.20	36	63	18	2.1	48.4
Hiyama	9	570	345	9.11	5.33	0.20	0.24	60	66	20	2.4	41.4
Hiyama	9	639	323	8.13	4.86	0.20	0.22	58	70	25	3.6	*
Hiyama	9	183	322	8.45	4.87	0.19	0.18	57	59	14	2.8	46.4
Hiyama	9	18	324	8.61	5.11	0.19	0.20	34	64	16	1.4	48.1
Hiyama	9	196	305	9.22	5.40	0.19	0.20	43	62	15	2.2	34.0
Hiyama	9	165	298	8.14	4.96	0.17	0.19	43	63	16	2.3	38.1
Shiraoi	2	(4)	329	9.33	5.48	0.16	0.17	35	54	14	3.1	24.0
Shiraoi	2	1	290	9.64	5.76	0.20	0.20	34	65	14	2.6	38.8
Shiraoi	2	2	338	11.47	6.73	0.23	0.21	58	63	19	3.8	32.6
Tomakomai	3	15	309	9.59	5.46	0.19	0.21	51	64	22	2.0	17.9
Tomakomai	3	582	291	6.10	3.42	0.12	0.11	31	35	9	1.2	0.0
Tomakomai	3	362	287	7.95	4.56	0.15	0.16	28	54	12	1.9	31.3
Tomakomai	3	515	306	8.13	4.66	0.15	0.14	27	47	11	1.3	30.9
Tomakomai	3	154	333	9.36	5.33	0.14	0.17	36	58	14	2.0	27.1
Tomakomai	4	95	357	12.22	7.20	0.26	0.29	79	96	24	2.1	43.3
Tomakomai	4	296	370	11.35	6.64	0.29	0.24	41	56	14	1.9	*
Tomakomai	4	447	364	12.39	7.17	0.27	0.28	47	89	21	1.7	49.4
Tomakomai	4	321	266	13.35	7.81	0.31	0.28	48	92	21	2.5	51.1
Average			314	9.49	5.48	0.17	0.18	41	58	15	2.3	29.1
Min.			242	6.10	3.42	0.05	0.07	15	24	5	1.2	0.0
Max.			370	13.35	7.81	0.31	0.29	79	96	25	3.8	51.1
C. V. (%)			9.2	18.2	18.6	35.3	31.0	36.7	28.7	36.7	28.4	48.6

* Germination test was not carried out because of insufficient amount of seed.

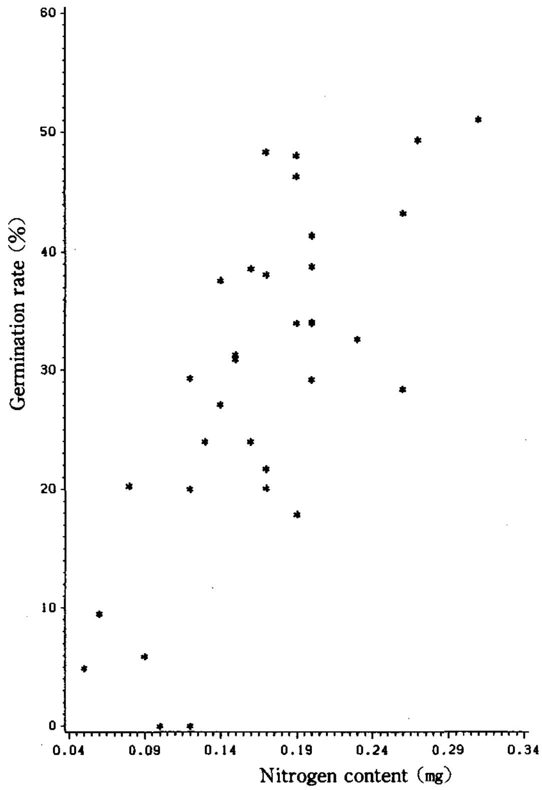

Fig. 6. Scatter diagram of germination rate to nitrogen content per grain of seed from mature cones.

Table 14. Coefficients of correlation between quantities of two chemical components per grain and between germination rate and each quantity of chemical components

	Weight	Carbon	Nitrogen	Mineral	P_2O_5	K_2O	MgO	CaO	Germination rate
Weight	1								
Carbon	0.9906	1							
Nitrogen	0.7196	0.7836	1						
Mineral	0.7304	0.7940	0.9460	1					
P_2O_5	0.5976	0.6344	0.7253	0.8197	1				
K_2O	0.7148	0.7737	0.8775	0.9597	0.7736	1			
MgO	0.5911	0.6524	0.8072	0.9114	0.8785	0.8959	1		
CaO	0.3576	0.3758	0.2657	0.3209	0.4762	0.3429	0.4399	1	
Germination rate	0.5791	0.6387	0.7297	0.7522	0.4986	0.7709	0.6330	0.1766	1

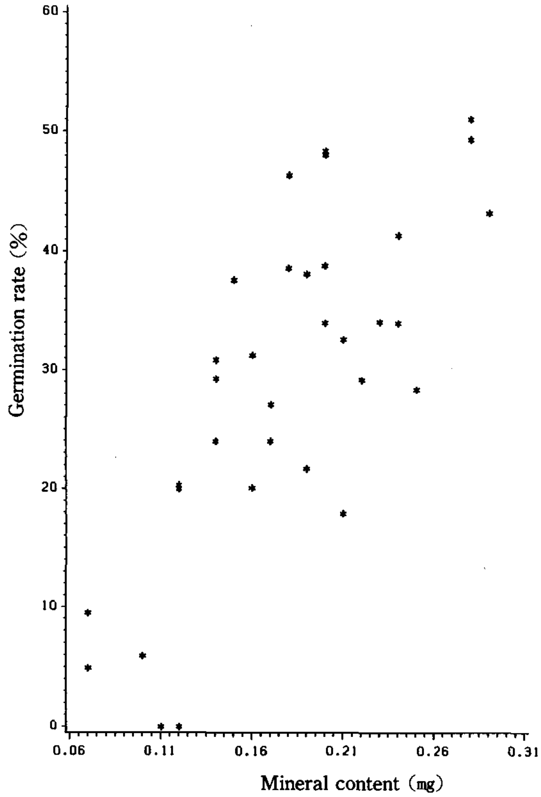

Fig. 7. Scatter diagram of germination rate to mineral content per grain of seed from mature cones.

high, in spite of its light weight, while that from the clones at Site No. 4 was generally low.

The relations between germination rate and content of such chemical components as nitrogen, total minerals, and potassium are shown in Figs. 6 (nitrogen), 7 (minerals), and 8 (potassium). A stereo diagram of germination rate to the contents of nitrogen and potassium are also shown in Fig. 9. The greater the quantity of these chmical components, the higher the germination rate, in nearly direct proportion. The coefficients of correlation between quantities of two chemical components per grain, between germination rate and grain weight, and between germination rate and each quantity of chemical components are shown in Table 14. The values between two chemical components or grain weight and each quantity were all significant at the 1% level except calcium quantity; especially high values were shown in the relations between the weight and carbon quantity, total minerals and potassium, as well as total minerals and magnesium. In relation to germination rate, the values were also all significant at the 1% level but calcium. Values more than 0.7 were obtained between germination rate and quantities of potassium, minerals, or nitrogen.

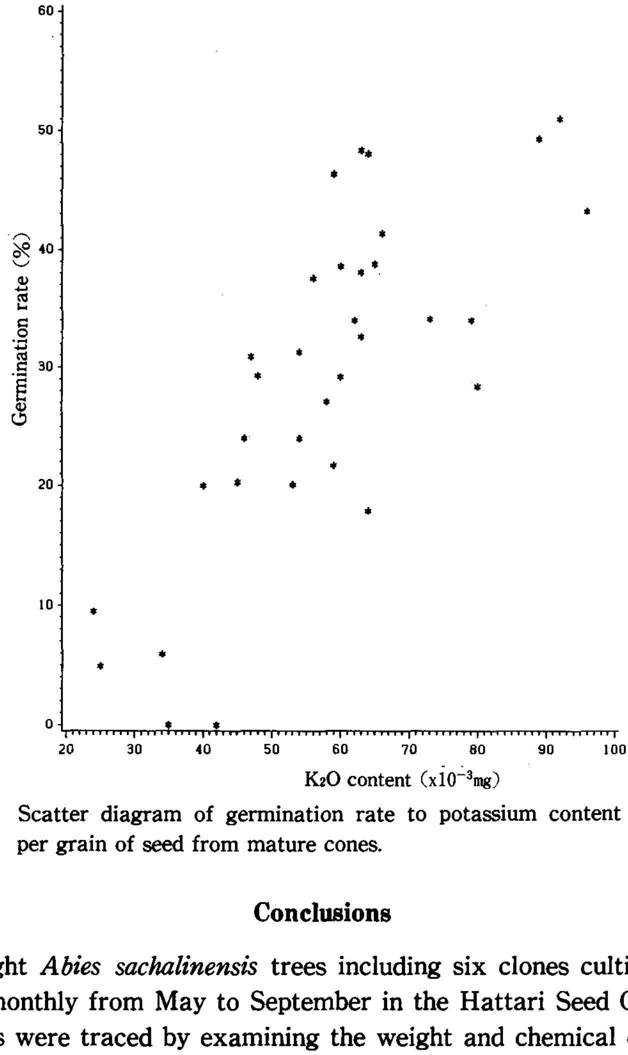

Fig. 8. Scatter diagram of germination rate to potassium content as oxide per grain of seed from mature cones.

Conclusions

Cones of eight *Abies sachalinensis* trees including six clones cultivated by grafting were collected monthly from May to September in the Hattari Seed Orchard, and their seasonal changes were traced by examining the weight and chemical components, separated into seed and scale after the collection in July. Moreover, variations of mature cones of the 36 trees including eleven clones were investigated chemically, and germination of the seeds was tested.

From these results, the following conclusions were obtained: The average cone weight was about 160 mg at the first collection of May and increased remarkably to 12,300 mg (80 times) at the last collection of September. On the whole, cones as light as Tomakomai 3—② in the beginning were very light at the end, while the heavy cones remained heavy until the end. Although the carbon content in the last stage was 54% in cones, that in seed was as high as 58% on the average, from which it was inferred that the seed contained a large quantity of fat and oil rich in carbon. The average nitrogen contained at 1.73% in the cones at the first collection decreased gradually to about 1% at the last collection, while the quantity per cone inreased markedly from 8 mg at the first collection to 133 mg at the last. That of nitrogen in seed was higher

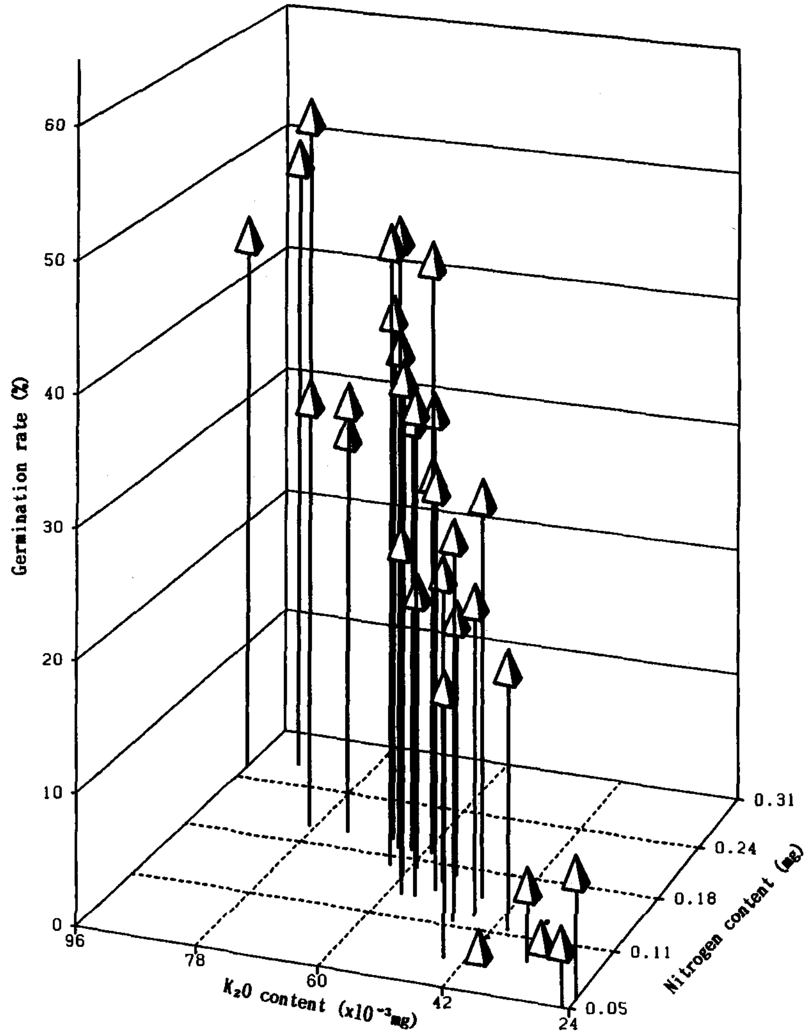

Fig. 9. Stereo diagram of germination rate to the contents of nitrogen and potassium as oxide per grain of seed from mature cones.

than scale, even though the weight ratio of seed to scale was 1 to 3. From this, it was inferred that nitrogen compounds such as protein, amino acid necessary for germination were synthesized in abundance in seed throughout the growth of cones. Total mineral content in cone was 6.6% on the average in May, and considerably decreased to 2.7% in September, but that in seed did not change much-only about 2%. The average contents of phosphorus and potassium as oxide in cones were 1.72% and 2.48%, respectively, in the first stage, but they decreased to about 0.5% and 1% in the last stage, while both the quantities per cone at the last collection increased strikingly to 30 times as much as those of the first collection. The magnesium content in cones was not so high, but that in seed was much higher than in scale. Calcium content was unexpectedly low, and sodium content was also extremely low. Generally, the heavy cones were rich in all the chemical components.

In the 36 mature cones, the average contents of carbon, nitrogen, mineral, phosphorus, potassium, and magnesium in seed were 57.7%, 1.8%, 1.9%, 0.43%, 0.61%, and 0.16%, respectively, while those in scale were 53.1%, 0.6%, 2.5%, 0.30%, 0.95%, and 0.12%. The chemical components which were richer in seed than in scale were carbon, nitrogen, phosphorus, and magnesium. Although the content of potassium important for germination was the highest in total minerals, it was rather higher in scale than in seed. The seed number per cone was 314 grains on the average. Among clones, the grains from Tomakomai 4 and Gamushi 5 were generally heavy and rich in nutrient substances, while those from Tomakomai 3 and Gamushi 102 were light and poor in these substances. The average germination rate was 29.1%, with a large coefficient of variation ranging from 0% to 51.1%, in which the seeds from Tomakomai 4 and Hiyama 9 showed high germination rates, but not from Tomakomai 3 and Gamushi 102. Coefficients of correlation between grain weight and each quantity of chemical components or quantities of two chemical components per grain were high and significant at the 1% level except calcium. Furthermore, those between germination rate and quantity of each chemical component were also significant at the 1% level, especially showed high values over 0.7 in the quantities of potassium, minerals and nitrogen per grain.

Hereafter, it is necessary to observe and manage the growth of trees transplanted in mountains from nurseries until their maturity. Although *Abies sachalinensis* trees are now very popular in Hokkaido, their seedlings are less resistant to frost injury and attack by such fungi as *Scleroderris* canker, and they generally have wood of low density and often wetwood in the heartwood. Accordingly, clones resistant to climatic damage and of good wood quality must be selected further from the clones now selected by phenotype.

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摘　　要

国有林においては，それぞれの環境に適したすぐれた樹種により造林を図るため，採種園を造成している。北海道の国有林では現在，トドマツ（*Abies sachalinensis* MAST.）とアカエゾマツ（*Picea glehnii* MAST.）およびカラマツ（*Larix kaempferi* CARR.）を主体として人工林・天然林より多くの精英樹を選抜し，その穂木を用いてつぎ木によりクローンを作り，45カ所の採種園に植栽されている。本研究では，岩内郡共和町にある発足採種園の6クローンを含む8個体のトドマツを用いて，球果の成長に伴う変化を重量と化学成分の両方から追求した。球果は1983年の5月（球花段階）から9月（完熟種子段階）まで毎月各個体毎に2—3個ずつ採取され，乾燥後重量を測定し，粉砕して炭素，窒素，無機物，リン酸，カリウム，マグネシウム，カルシウムおよびナトリウムの含有率と，球果，全種子（7月採取から種子と鱗片に分ける）と種子粒および鱗片（果軸を含む）当たりの含有量を求めた。さらに完熟球果については，36個体11クローンについて同様の分析を行うとともに，翌年その種子を圃場に播種して発芽率を測定し，種子粒の重量，成分と発芽率との関係を調べた。その結果は，次の通りである。

1．5月に採取した球果（未受精の球花）の平均重量は，157 mgであったが，9月の完熟球果では12,292 mgとおよそ80倍にも成長していた。その中で，とくに苫小牧4や俄虫5のクローンの球果は重く，これに対し苫小牧3のそれは軽かった。一般に初期に重い球果は最終まで重く，逆に軽いものは最後まで軽かった。

2．球果の炭素含有率は，5月段階の46.6%から次第に上昇し，9月に54.0%に達した。この含有率の増加は，種子の炭素含有率の上昇によるもので，完熟種子ではおよそ58%にも達したのに対し，鱗片のそれは52.7%で，7月採取の球果から含有率は殆ど変化していなかった。この事実は種子中に炭素含有率の高い油脂類が豊富に合成・蓄積されていくことをうかがわせた。

3．球果の窒素含有率は，5月段階で平均4.73%と高かったが，季節の経過とともに減少し，9月には約1%となった。一方球果当たりの窒素含有量は，8 mgから133 mgへと著しく増大した。また種子中の窒素量は鱗片にくらべて，その重量比が1：3であるにもかかわらず，むしろ多く，球果の成長とともに種子中のタン白質やアミノ酸などの窒素化合物が著しく増大していくことを示した。

4．球果中の総無機物は，5月の段階で平均6.6%であったものが，9月には2.7%と減少したが，球果当たりの平均無機物量は11 mgから333 mgと増加した。

5．無機物中の最大のものは，カリウムであった。リン酸とカリウムの含有率はそれぞれ5月段階の平均1.72%と2.48%から，9月段階のおよそ0.5%と1%へと減少した。しかし球果の成長とともに両者とも，その含有量は約30倍にも達した。種子中でのリン酸とカリウムの含有率は，その間あたり変化しなかった。一方マグネシウム含有率は，前者にくらべて著しく低かったが，完熟種子では鱗片よりかなり高かった。カルシウム含有率は，マグネシウムよりもさらに低く，そして種子のそれは，カリウムと同様鱗片よりもむしろ低かった。ナトリウムの含有率は，無視できる程低かった。

6．完熟種子の炭素，窒素，総無機物，リン酸，カリウム，およびマグネシウムの平均含有率は，それぞれ57.7，1.8，1.9，0.43，0.61%および0.16%であり，それに対して鱗片では，それぞれ53.1，0.6，2.5，0.3，0.95%および0.12%であった。結局種子は鱗片より，炭素，窒素，リン酸，マグネシウムなど発芽に関係があると思われる物質に富んでいた。

7．1球果当たりの平均種子数は314粒で，その変動係数は9.2%と低かった。

8．種子粒をクローン別に比較すると，苫小牧4および俄虫5が一般に重量が重く，栄養に富んでおり，苫小牧3，俄虫102は軽く，栄養物質の含有量も少なかった。

9．種子発芽率の平均は29.1%で，その範囲は，0%から51.1%であり，変動係数は48.6%と高かった。クローン別に発芽率の高いものは，苫小牧4と檜山9であり，低いものは，種子重量の軽い苫小牧3および俄虫102であった。

10．種子粒の重量と各成分および2成分間の相関係数は，カルシウム含有量を除いていずれも高く，重量の重いものほど，いずれの栄養物質にも富んでいることが分かった。

11．発芽率と種子成分との関係では，カルシウムを除いて，いずれも1%水準で有意であり，とくにカリウム，総無機物，窒素との間の相関係数は0.7以上にも達する高い値がえられた。

12．今後は，クローン別にこれら造林木の生育過程を考察し，トドマツの欠点である幼齢時の枝枯れ病害や，気象害に対して抵抗性があり，材質的にもすぐれたものを，さらに選抜していく必要がある。