Relationships between Germinability of Rice Seeds at Low Temperature and Subsequent Early Growth of Seedlings

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In Hokkaido, the northernmost island of Japan, direct-sowing culture of rice on flooded paddy fields was chiefly practiced about forty years ago. Nowadays, owing to the adoption of transplanting by machines, the direct-sowing is very rare. However, because of its labor saving features it is expected that direct-sowing will be employed again in the near future by some farmers as a means to cut down rice production costs.

To stabilize the direct-sowing culture in cool regions such as Hokkaido, it is essential to stabilize and promote initial seedling growth and formation of productive tillers in an early stage. However, the initial growth and tillering depend on seed germination and seedling establishment. Varietal difference in low temperature germinability (LTG) is very important to stabilize germination, and elongation of initial seedlings is a necessary factor which determines seedling establishment.

The author[6,7] conducted studies on genetic and breeding factors of LTG. The outline of the results obtained is as follows; The varietal difference in LTG was distinct at 13–15°C of germination temperature 10 days after sowing, and the degree of germinability was represented by germination coefficients (Germination percentage/Average number of days required for germination). Frequency distribution of this characteristic in F_2 populations showed a continuous variation, so that the genetic behavior was predicted as quantitative, indicating dominance of higher germinability and recessiveness of lower germinability at low temperatures. The number of effective controlling factors in the embryo was estimated at about five. Heritability in early generations was fairly high. Parent-offspring correlation in F_2 seeds to F_3 strains was high, and notable effects of selection at early generation were shown.

On the basis of this result, the author attempted to make clear the relationship between LTG of different varieties and plant factors which constitute the initial growth of seedlings.

Field and indoor experiments were conducted using local, old and new varieties which have been bred in Hokkaido and possess different degrees of LTG.[4,5,6,7] The LTG was classified by the germination coefficients, tested at 15°C for 10 or 15 days[6] using a plastic schale of 9 cm in diameter with one sheet of filter paper as germination bed. The water was supplied by 4 cc at the beginning of germination test and 1 cc every three days. Outdoor experiments were conducted by direct-sowing to a flooded field with water depth of 3–6 cm.[6] Other experimental conditions will be indicated when needed.

Elongation at an early growth stage of seedlings

One of the problems related to direct-sowing in cool regions is that the direct-sown plants need a longer growth duration and the growth is apt to be delayed as compared with transplanted seedlings. To solve this problem, early sowing should be made as soon as water temperature attains the minimum germination temperature. At such low water temperature, germination and elongation of young buds

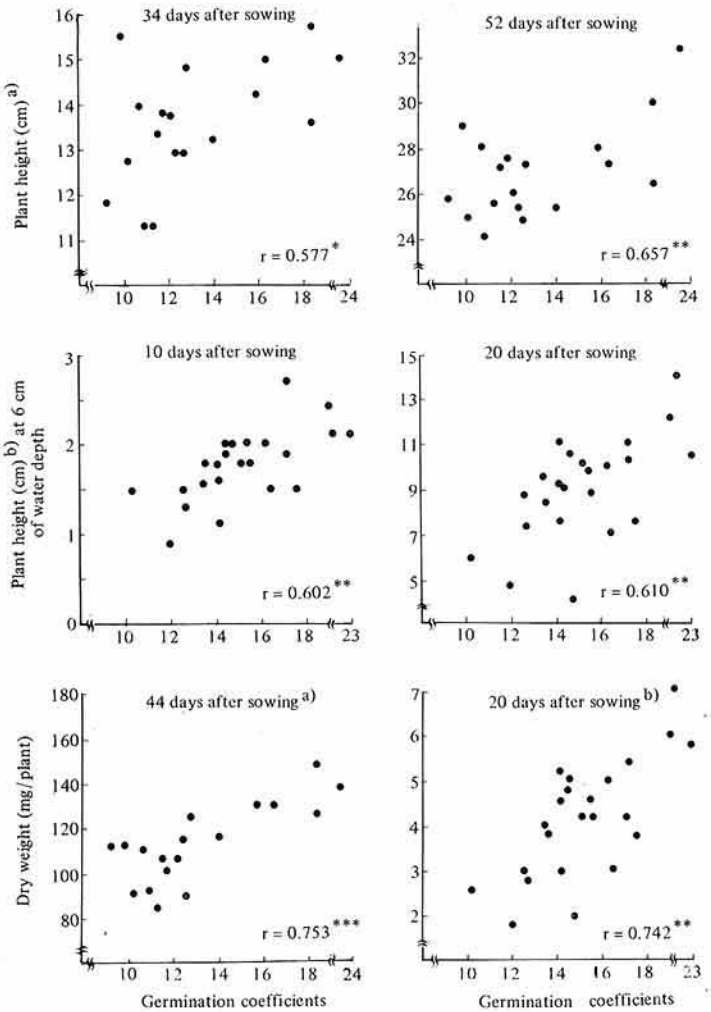

Fig. 1. Correlations of germination coefficients to plant height and dry matter weight of seedlings

Notes: (*), *, **, *** Significant at 10%, 5%, 1% and 0.1% level, respectively. Same in other figures and tables

a) Direct-sowing to flooded field

b) Laboratory experiment with water depth of 6 cm

Mean water temperature after sowing (°C)

No. of days after sowing	a)	b)	Nursery bed
1–5	12.7	18.5	22.8
6–10	13.9	17.3	20.9
11–15	17.2	21.2	19.3
16–20	17.0	24.9	22.9
21–25	15.0		17.2
26–30	20.2		
31–35	20.7		
36–40	22.0		
41–45	21.5		
46–50	20.7		

should begin as soon as possible in order to make possible an early emergence of sprouts above the surface of irrigation water.

1) Plant height, dry matter weight, and length of leaf blade of young seedlings

Relationships observed among LTG, plant height, and dry matter weight of young seedlings are shown in Fig. 1. Correlation between germination coefficients and plant heights was found to be statistically significant at a higher level. But, with the passing of days after sowing the water temperature increased and the highly significant correlation became less significant statistically. In a vinyl house (high temperature conditions), the correlation was insignificant (r=0.141). On the other hand, highly significant and positive correlations were found between germination coefficients and dry matter weight of seedlings 44 days after direct-sowing to a flooded field and 20 days after sowing to a flooded soil in the laboratory. However, insignificant correlations were found in a vinyl house (r=0.402). As to the relationship between the germination coefficient and the length of each leaf blade, the 2nd leaf and 3rd leaf showed highly significant correlations followed by the 4th and 5th leaf with decreasing significance (Table 1).

2) Leaf number index

Leaf number index of seedlings seems to be an indicator of growth speed. Correlation between germination coefficients and leaf number index at an early stage of growth was high and positive (Table 1).

Table 1. Correlation of germination coefficients to leaf blade length and leaf number index at an early growth stage

Leaf blade length			Leaf number index	
Leaf order		r	No. of days after sowing	r
Direct-sowing	2nd	0.526*	38 days	0.534*
	3rd	0.645**	41	0.447(*)
	4th	0.615**	47	0.295
	5th	0.473(*)		
3rd leaf in transplanting		0.073		

Temperature condition is same as that of Fig. 1.

These data show that there exists a significantly positive relationship between LTG and elongation of direct-sown seedlings at the early stage of growth under relatively low water temperature conditions. It clearly indicates that the higher the LTG, the greater is the elongation at the early stage of growth.

Emergence of radicles and some properties of roots at an early stage

It is considered that seedling establishment depends on rooting ability and root development. To clarify the relationship between LTG and ability of roots to develop at an early growth stage, the author made experiments by using 23–46 old and new varieties.[4,5]

Emergence of radicles of seminal roots prior to germination at 15°C was not observed at all with any seed. The number of days from germination to the radicle emergence varied from 2 to 4 days among all varieties used and about 90% of the seeds commenced the radicle emergence 6–8 days after germination (Table 2). Curves of percentage of emerged radicles plotted against time shows that the radicle emergence began 6–9 days and ended 12–14 days after sowing. These curves closely resemble curves of percent germination at 15°C, with a time lag of 2–4 days (Fig. 2). This result is inconsistent with Nakamura's and Takahashi's reports.[2,8]

A significant varietal difference was observed in both of rooting coefficient (calculated by the same way as germination coefficient) and the number of days from germination to radicle emergence. Although the correlation between the two was highly significant, showing r=−0.387,** no correlation was recognized between the germination coefficients and the number of days from germination to the radicle emergence (r=−0.039). Though a partial correlation (r'=−0.919**) between the above two characteristics can be calculated by

Table 2. Varietal differences of radicle emergence at 15°C

Rooting* ability	Name of varieties	Germination coefficients	Rooting coefficients	Percentage of radicle emergence 9 days after sowing	Mean days to radicle emergence	Number of days from germination to first radicle emergence	Number of days from germination to end of radicle emergence
High	Iburiwase	26.60	12.55	91.0	8.0	3.5	4.2
	Hayayuki	20.77	12.31	91.5	8.1	3.0	3.3
	Sakigake	20.65	11.76	84.0	8.6	2.9	3.7
Middle	Hokkai No. 116	16.95	9.79	44.5	10.3	3.2	4.3
	Eiko	20.77	9.52	23.5	10.5	3.1	3.8
	Shirayuki	20.65	9.21	16.0	10.9	3.3	4.0
Low	Hokkai No. 95	12.98	8.07	5.5	11.9	3.4	4.3
	Shinsetsu	12.46	7.79	5.5	12.4	3.2	4.5
	Fukuyuki	13.32	7.57	0	12.8	3.6	5.4
Mean ± S**		16.13±2.95	9.51±1.11	32.8±24.85	10.6±1.08	3.4±0.33	4.2±0.42
L.S.D.	5%	3.79	0.73	24.1	0.8	0.6	0.7
	1%	5.07	0.98	32.2	1.1	0.8	0.9

* Rooting means radicle emergence of seminal root.
** Calculated with 46 varieties
Rooting test was conducted in the same conditions as in germination test.

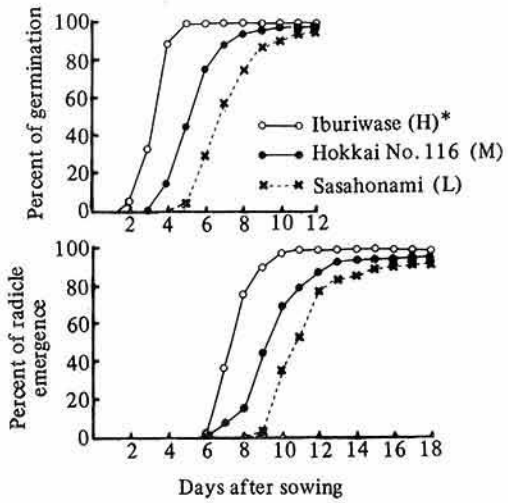

Fig. 2. Germination and emergence of radicle at 15°C
* LTG: high (H), middle (M) and low (L)

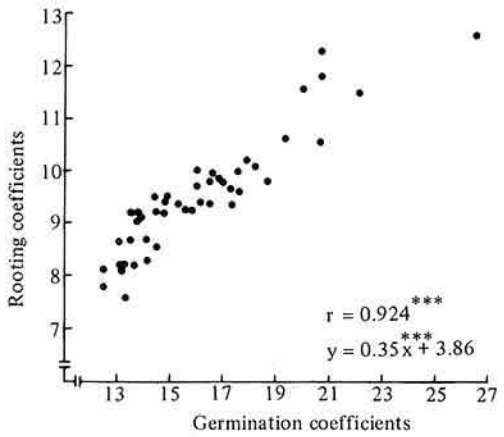

Fig. 3. Relationship between germination coefficients and rooting coefficients at 15°C

eliminating the effect of the germination coefficients (Data not presented), it is assumed that the germination at low temperature is not always accompanied by the initiation of radicle emergence of seminal root which is controlled so as to occur after the germination. Therefore, it is possible that both characteristics are governed by different factors to some extent.

Fig. 3 shows the relationship between the

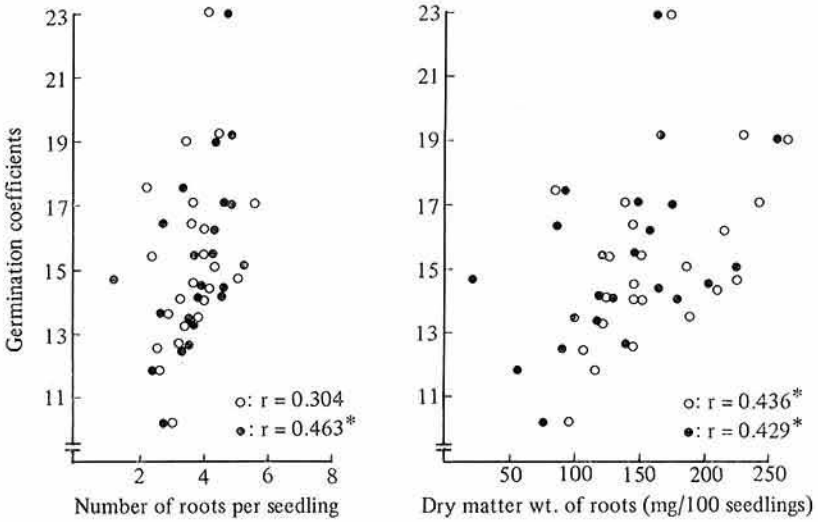

Fig. 4. Correlations of germination coefficients to number of roots and dry matter weight of roots 20 days after sowing
Water depth ○ : 3 cm, ● : 6 cm

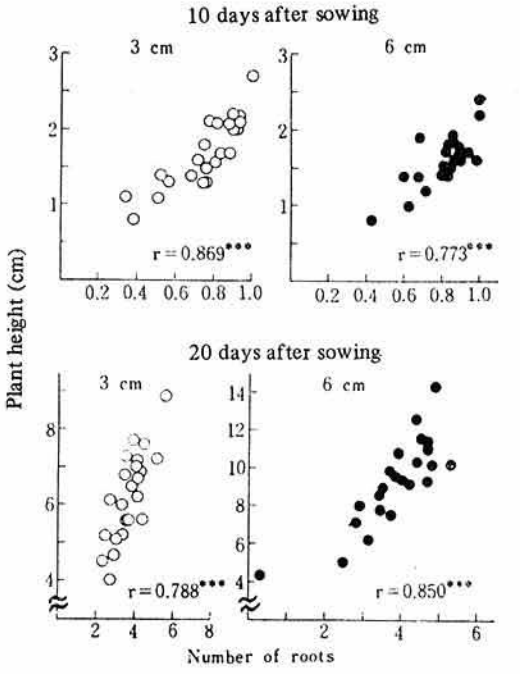

Fig. 5. Correlation between number of roots and plant height of seedlings at 3 and 6 cm of water depth

germination coefficients and rooting coefficients: r=0.924.***

With respect to the relationship between LTG and some properties of roots (number of roots, maximum length of roots and dry matter weight of roots), significant or at least positive correlations were observed with 10-day and 20-day old seedlings, irrespective of different water depth (3 cm and 6 cm). The correlations are more clear with 20 day old seedlings (Fig. 4). Regarding the relationships of LTG to the number of roots, the maximum length of roots and the weight of seedlings, very high correlations were noticed, irrespective of different water depth and different date after sowing (Table 3). Even at a relatively early stage after sowing, the same trend of varietal differences were observed under different conditions such as different water depth. On the other hand, a highly positive correlation was also observed between plant height and root development (Fig. 5). From the partial correlations calculated among LTG, plant height and root development, it was found that there exists a significant correlation between the plant height

Table 3. Correlation coefficients between number of roots and some properties of roots of seedlings

			Root length				A*)	
	No. of days after sowing		10 days		20 days		20 days	
	Depth of water (cm)		3	6	3	6	3	6
No. of roots	No. of days after sowing	Depth of water (cm)						
	10 days	3	0.896***	0.889***	0.689***	0.464*	0.812***	0.646**
		6	0.789***	0.574**	0.450*	0.462*	0.470*	0.573**
	20 days	3	0.725***	0.562**	0.645**	0.590**	0.766***	0.269
		6	0.423*	0.350	0.434*	0.745***	0.293	0.841***

A*): Wt. of roots per 100 seedlings

and the root development, apart from the effect of LTG (Table 4). Judging from these results, the positive correlation observed between LTG and root development at an earlier stage can be regarded as being brought about through the plant height.

Establishment of seedlings

Establishment of seedlings in the direct-sowing is essential in promoting seedling growth and obtaining productive tillers as early as possible. As mentioned above, significantly positive correlations were recognized with different varieties among LTG, seedling elongation at an early stage of growth, rooting ability and root development of seedlings at low temperature. Therefore, it is assumed that such relationships may have an important effect on the success or failure of seedling establishment. To ascertain whether the above assumption is correct or not, an experiment using 36 varieties was carried out at low and high water temperature conditions (Table 5), and the relationship between LTG of different varieties and their degree of seedling establishment was examined.[5)]

The correlation between LTG and percentage of seedling establishment at the above temperature conditions was relatively low, but significantly positive. At high water temperature, the correlation was not high, but if the 4 varieties showing great deviations from others are excluded, a significantly positive correlation was also obtained (Fig. 6).

Table 4. Partial correlations among germinability, number of roots and plant height of seedlings

Partial corr.	No. of days after sowing			
	10 days		20 days	
	Depth in water			
	3 cm	6 cm	3 cm	6 cm
r 13.2	−0.370	−0.232	0.33	−0.091
r 23.1	0.873***	0.754***	0.763***	0.806***
r 14.2	−0.053	0.195	0.330	−0.087
r 24.1	0.606***	0.512*	0.689***	0.652***

1: Germinability at low temperature
2: Plant height of seedlings
3: No. of roots per 100 seedlings
4: Length of the longest root

The reason why very high correlations were not obtained contrary to the expectation from the above assumption, is that the seedling decay occurred more in number at the low temperature, while floating seedlings and turned-down seedlings occurred more at the high temperature. With respect to the relationships between percent establishment and dry matter weight of seedlings and of roots, significantly positive correlations were also observed in both water temperature conditions (Fig. 7). From these results, the assumption that the relationships between LTG and elongation of seedlings and of roots at an early stage of growth contribute to the seedling establishment was proved to be correct.

Table 5. Mean water temperature in the experimental paddy field after sowing

No. of days after sowing	Sowing time	
	Early (1968)	Late (1969)
1～ 5	14.6°C	23.0°C
6～10	13.9	22.9
11～15	19.8	24.3
16～20	20.2	22.9

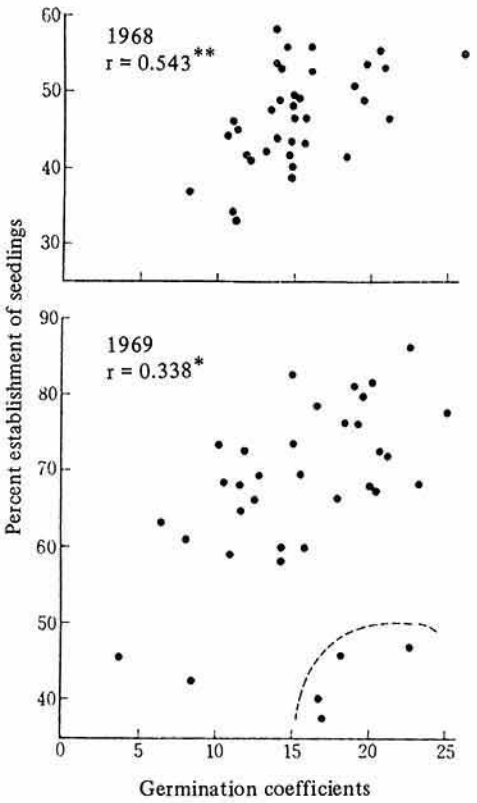

Fig. 6. Correlation between germination coefficients and percentage of establishment of seedlings

Concluding remarks

It was made clear that significantly positive correlations exist among low temperature germinability, degree of elongation of seedlings and that of roots at the initial growth stage after sowing. It was also proved that desirable combinations of these factors can contribute largely to the seedling establishment. Thus, to sum up these results, it becomes clear that the low temperature germinability is a useful characteristic for ensuring good seedling establishments in direct-sowing on flooded paddy fields in cool regions.

On the contrary, the use of calcium peroxide for coating seeds was found very effective in promoting emergence and establishment of rice seedlings in direct-sowing on flooded fields.[3,4] Moreover, it is said that the varietal difference of LTG is removed by heat treatment of seeds.[1] Nevertheless, the use of calcium peroxide and heat treatment can not

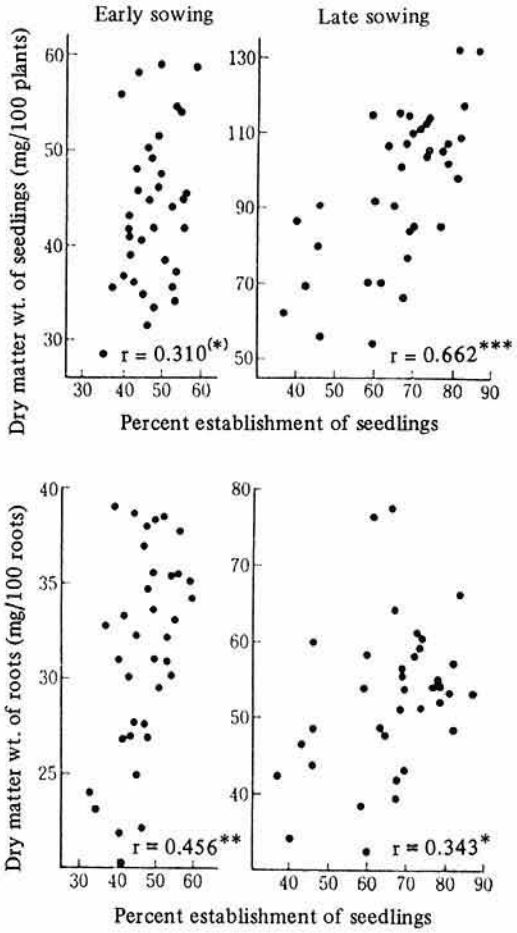

Fig. 7. Correlations of percentage establishment of seedlings to dry matter weight of seedlings and roots

substitute for the importance of varietal characters of high LTG and good initial growth at low temperatures.[4] Breeding for high LTG must be promoted.

The result of this study indicates that the breeding for LTG is also effective for the selection of better elongation of seedlings and higher rooting ability which are required by varieties suitable for direct-sowing in cooler regions.

A fact that some of the correlations found in Hokkaido varieties do not apply to some Indica varieties (Sasaki, unpublished) has to be considered in selecting parental material for the breeding.

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