Breeding and Cultivation of Japanese Species of Genus *Coix* as a Fodder Crop

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Introduction

The genus *Coix*, believed to be originated in India and Southeast Asia, is a relative of maize which belongs to Maydeae, and is one of the five oriental genera of Tripsaceae, i.e. *Coix*, *Trilobachne*, *Polytoca*, *Sclerachne* and *Chionachne*. *Coix* was cultivated in India in ancient days as indicated in Vedic literature (B.C. 1500–B.C. 800). It is now widely distributed over tropical, subtropical, and temperate zones as wild species, and is cultivated in some districts. Seven species of *Coix* have been identified so far, based on the shape of leaves and seeds, although no generally accepted taxonomy has been established yet. In *C. Lacryma-Jobi* L, seven varieties have been reported so far. Studies on the genus *Coix* have been confined only to morphological and cytological aspects[1,17,18].

In Japan, two major types of *Coix* have been known, i.e. Hatomugi (*C. Ma-yuen* Roman, *C. Lacryma-Jobi* L. var. *Ma-yuen* Stapf. etc.) and Juzudama (*C. Lacryma-Jobi* L). Hatomugi is an annual type and its seeds have been used as drug and fodder, while Juzudama, a perennial wild type, is grown under unfavorable environments, especially ill-drained conditions. Though it is not clear when Juzudama was introduced to Japan, it has been known since fairly early days as a wild plant, while some old documents indicated that Hatomugi was introduced from China at the beginning of the 19th century.

The author carried out experiments on the interspecific crossing between Hatomugi and Juzudama and polyploidization with an aim of developing perennial fodder *coix* with high-yielding potential.

Experimental results

The experiment was carried out at the Kyoto Prefectural University during a period from 1955 to 1976. Results are summarized as follows:

1) Geographical variations in morphological characters

Many ecotypes (hereafter referred to lines) of Hatomugi and Juzudama were collected from all parts of Japan to examine their morphological characters. Juzudama showed a greater variation in plant height than Hatomugi, ranging from 72 to 181 cm as compared to 115 to 148 cm in the later. Juzudama is shorter in plant height at higher latitudes, while such a tendency was not observed with Hatomugi. Juzudama exceeded Hatomugi in number of tillers. At lower latitudes, Hatomugi headed earlier than Juzudama, but at higher latitudes some lines of Juzudama headed earlier than Hatomugi, although early maturing types of Hatomugi were also observed.

Variations within a line (coefficient of variation) in plant height, number of tillers and heading date indicated that Juzudama has significantly smaller coefficients with increasing latitude, especially for plant height. Such geographical or ecological differences between wild and cultivated species of *Coix* in Japan seem to be caused by the difference in the date of introduction and the way of utilization[13].

2) Pollen morphology

As pollen morphology is a major field of palynology, the surface structure of pollen membrane was compared with electron microscope among Hatomugi, Juzudama, F_1 hybrids between them, tetraploid *Coix*, and corn (*Zea Mays* L) with an aim of knowing the kinship of these plants. It was found that the sexine of pollen membrane is covered by fine spinules, and there is no recognizable difference in the surface structure among these plants, except a slight difference in size and shape of spine, and a considerable difference in the structure of germ pores of pollens. This result suggests a considerable similarity among the species of *Coix*, as well as between *Coix* and *Zea*[4].

3) Characters of F_1 plants

Seed fertility of Hatomugi and Juzudama was more than 90% in natural pollination, and their selfing rate was proved to be as high as 85% by isolated cultures. Interspecific crossability between them was fairly high, showing 43.1 and 50.3% in reciprocal crosses. Significant heterosis was recognized in many characters of F_1 hybrids, especially with plant height, number of tillers, leaf length and plant weight. In addition, the F_1 plants showed particularly good regrowth after cutting, in terms of plant height and number of tillers. However, the pollen and seed fertilities of the F_1 plants were only 60% and 30% respectively. All the F_1 plants survived winter in open field, and their growth in the next year was as good as in the first year. These facts suggest the usefulness of the F_1 hybrid as a fodder crop[2].

4) Cytogenetical features

Cytogenetical study was carried out to find out the cause of the decreased pollen fertility in the F_1 hybrids. Both Hatomugi and Juzudama have 20 somatic chromosomes with karyotype formulae shown in Fig. 1. The shape of E chromosome is clearly different between the two species, and in the meiosis of pollen mother cells of the F_1 plants 82% of the total number of cells examined showed 10 II, whereas 14% showed 9 II+2 I, and a few cells 4 I and 6 I. The occurrence of univalent chromosomes mostly due to the E chromosome is regarded the cause of the reduced pollen fertility in F_1 hybrids[5].

5) Segregation in F_2 population

Early heading and late heading plants were segregated with a ratio of 52 to 285, which leads an assumption that the time of heading is determined by 3 genes. Plant height showed a trimodal distribution consisted of parental and F_1 modes (Fig. 2), indicating that plant height is determined by a few genes with relatively large effectiveness. Penotypic and genetic correlations between plant height and other characters showed that plant height has high positive correlations with heading date, leaf length, plant weight, and pollen fertility, but is negatively correlated with number of tillers (Fig. 3). As tall plants were all late-maturing, the breeding for an early maturing tall type would be difficult. Winter-survival ability was apparently greater with late-maturing tall plants than early-maturing short plants[6].

6) F_3 lines

From 43 F_2-plants taken at random F_3 lines were derived. Mean plant heights of F_3 lines ranged from 110 to 250 cm continuously. Coefficient of variation of plant height was smaller in tall lines, giving the correlation of -0.823 between plant height and the coefficient of variation. Phenotypic and genetic correlations between plant height and some other characters were calculated by the analysis of variance and covariance. Plant height was negatively correlated with number of tillers, but was positively correlated with heading date (Table 1).

Heritability of characters was estimated by using correlation and regression between F_2 individuals and F_3 lines and further by the analysis of variance. Heritability estimated by correlation for plant height and for head-

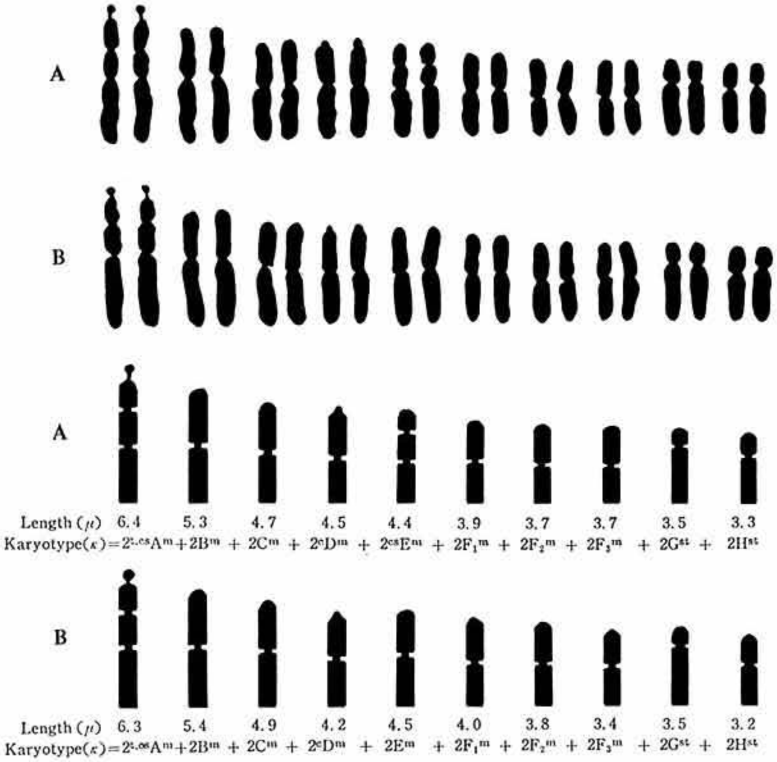

Fig. 1. Somatic chromosomes and karyotype of Hatomugi (*Coix Ma-yuen* Roman.) and Juzudama (*Coix Lacryma-Jobi* L.)
A : Hatomugi, B : Juzudama

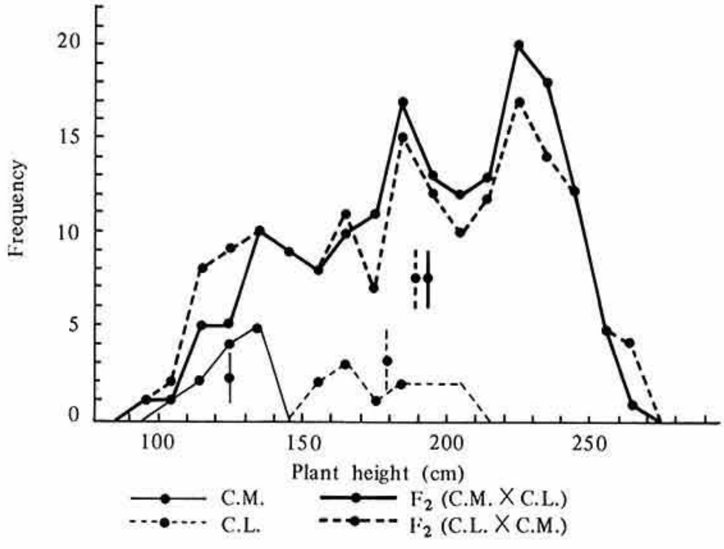

Fig. 2. Frequency distributions of plant height of Hatomugi, Juzudama and F_2 populations
C.M. : Hatomugi, C.L. : Juzudama

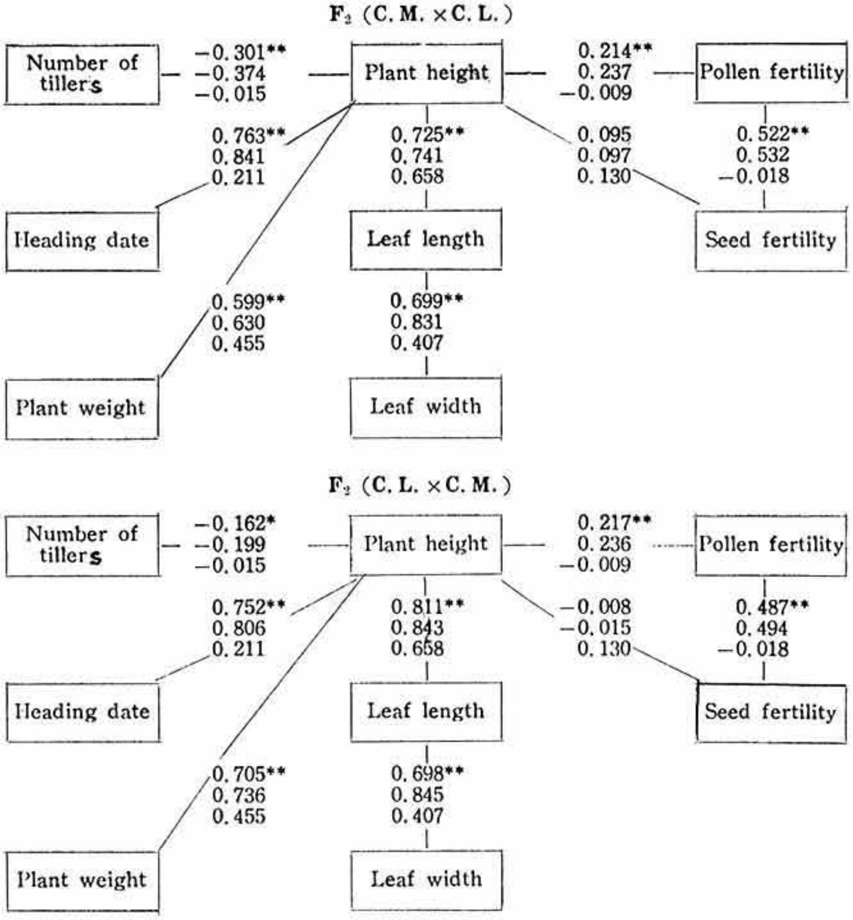

Fig. 3. Phenotypic, genetic and environmental correlation coefficients between main characters of F_2 population

Each set of three figures indicates phenotypic, genetic, and environmental correlation coefficients in that order.
* Significant at the 5% level
** Significant at the 1% level

Table 1. Phenotypic, genetic and environmental correlation coefficients between plant height and some other characters of F_3 lines

Correlation	Plant height~No. of tillers	Plant height~Heading date	Plant height~Seed fertility
^rP	−0.6421**	0.8799**	0.1688
^rG	−0.8931	0.9477	0.1845
^rE	−0.4948	0.4374	0.2274

^rP, ^rG and ^rE show phenotypic, genetic and environmental correlation coefficients respectively
** Significant at the 1% level.

ing date was very high, i.e. more than 0.8 for both cases. Heritability of number of tillers was 0.5, but that of pollen and seed fertility was hardly recognized because of recovered fertility in F_3 plants. Thus, it is expected that tall, late-maturing and high-yielding lines can be obtained in later generations[10].

7) F_4 and F_5 lines

By selecting tall individuals of tall F_3 lines, 51 F_4 lines were obtained. Plant height variance in F_4 line was generally smaller than in F_3, and the segregation of plant height emerged only in few lines. Phenotypic and genetic correlation between plant height and heading date was highly significant, but the negative correlation between plant height and number of tillers observed in early generations was not recognized in F_4. Heritability estimated by correlation and regression between F_3 and F_4 plants was high for many characters, especially for heading date (Table 2). Among F_4 plants appeared many promising lines that are tall and fixed for plant height.

Table 2. Heritability calculated by means of correlation and regression between F_3 individual and F_4 lines

Character	Correlation coefficient	Regression coefficient
Plant height	0. 3532*	0. 3679*
Number of tillers	0. 4797**	0. 1742**
Heading date	0. 8116**	0. 9945**
Pollen fertility	0. 4902**	0. 4494**
Seed fertility	0. 5663**	0. 3815**

** Significant at the 1% level.
* Significant at the 5% level.

Table 3. Heritability calculated by means of correlation and regression between F_4 individual and F_5 lines

Character	Correlation coefficient	Regression coefficient
Plant height	0. 2565	0. 3448
Number of tillers	0. 2820	0. 1274
Heading date	0. 4981**	0. 4211**
Pollen fertility	0. 2884	0. 1140
Seed fertility	0. 2421	0. 1232

** Significant at the 1% level.

Plate 1. Tall F_5 lines developed from the interspecific hybridization between Hatomugi (*Coix Ma-yuen* Roman.) and Juzudama (*Coix Lacryma-Jobi* L.), as compared to Hatomugi, a short plant in the right side. Length of the measure shown is 200 cm.

Most of F_5 lines obtained through a more intensive selection for plant height in F_4 seemed to have been fixed already for plant height, in spite of the open pollination within F_4 lines (Plate 1). Mean plant height for all the F_5 lines was taller than that for all the F_4 lines. In the F_5 generation, a high correlation of 0.67 was still recognized between plant height and heading date, but no correlation was observed among other characters. Heritability was recognized for heading date, but not for other characters (Table 3). Seed germination ability was increased to more than 80% with the advance of generation, so that promising lines can be propagated by seeds[11].

8) Polyploid plants

To evaluate polyploid breeding, autotetraploid Hatomugi and allotetraploid F_1 of Hatomugi × Juzudama were produced by the colchicine treatment. The autotetraploid Hatomugi showed a slower growth than the diploid one, and was inferior with all important characters at the maturity, suggesting that the polyploidy is of no value in the breeding of Hatomugi. On the contrary, the allotetraploid F_1 plants grew faster and all characters except water content were greater than both of the parental species. Especially, important characters such as plant height, leaf length and width, and plant weight showed significant increases. Pollen and seed fertilities of auto- and allotetraploids were lower than those of parental species. It is suggested that the allotetraploid F_1 plants are promising for the use as a fodder crop[3].

9) Resistance to submersion

Submersion resistance of the allotetraploid, the two parent species, and their diploid F_1 hybrid was compared. All of the used materials, except Hatomugi, were highly resistant to submersion[7].

10) Sensitivity to radioactivity

Dry dormant seeds of Hatomugi, Juzudama, diploid and tetraploid F_1 plants, and tetraploid Hatomugi were irradiated by X-rays of 5–20 kr. Judged from the effect of the treatment on seed survival and germination rates, plant height and seed fertility, it can be concluded that 2X F_1 is most resistant, and 4X Hatomugi and 4X F_1 are less sensitive than 2X Hatomugi and Juzudama[8].

11) Cutting experiment

Hatomugi, Juzudama, a F_4 line of their hybrid, and 4X F_1 plants were subjected to the cutting treatment, by which plants were cut 1–4 times during their growth period. As the cutting was repeated, the number of tillers was increased in all plants, but it was most remarkable with the F_4 line and Juzudama. Regrowth as expressed by plant height and weight of harvests were greatest with the F_4 line. Total harvest weight in a growth period of the F_4 line amounted to 7,100 kg per 10a, which is as much as twice that of parental species (Fig. 4). Two to three cuttings during a growth period seemed to be most effective.

Chemical composition of the harvests was determined at each cutting. Crude protein and crude ash decreased with plant growth, but increased as the cutting was repeated. On the other hand, crude fiber and nitrogen-free extract increased with plant growth, but decreased with cuttings, while crude fat content remained almost unchanged. As a whole, the chemical composition showed no remarkable difference among species and hybrids used, and was similar to that of other grasses of Gramineae[9]

12) Response to planting density

Hatomugi, Juzudama, and a F_5 line selected for tallness were grown at 3 levels of mix-planting (30, 60 and 90 cm spacing). At a dense planting, plant height increased, but number of tillers and dry weight/plant were decreased remarkably. Differences in the response among three materials used were not clearly recognized, but short plants were liable to be influenced by tall plants. The dense planting gave a greater harvest due to the in-

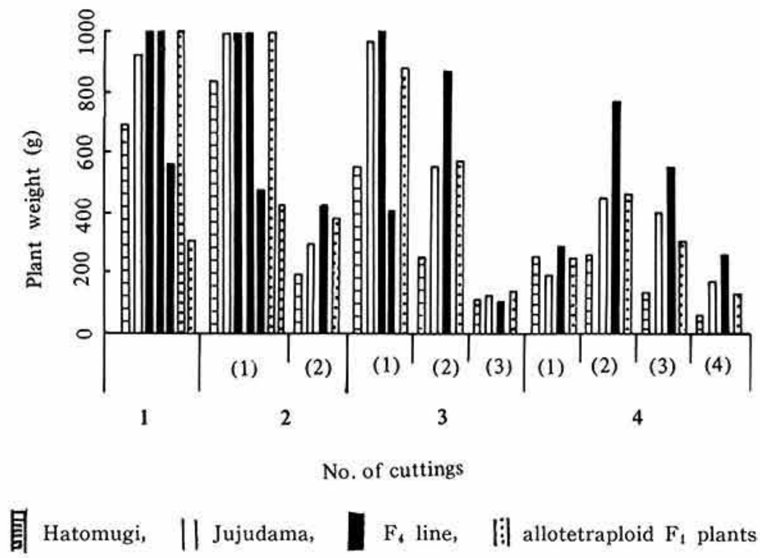

Fig. 4. Weight of harvests at each cutting of *Coix* species and hybrids

creased number of plants, although the dry weight/plant was less. It suggests that a relatively dense planting would be needed for high yields.

In addition to the above-mentioned studies, the author has undertaken the following works: Morphological and cytological studies of F_1 hybrids between Thai and Japanese *Coix* varieties[14], productivity of improved varieties in direct sowing culture[15], and performance of new *Coix* strains under submerged condition[16].

Conclusion

The use of the genus *Coix* as a fodder crop is considered to be very promising, but many problems still remain to be solved: genome analysis and combining ability for the better use of heterosis, methods of selection in breeding, improved cultural practices, etc. Collection of foreign genetic stocks is also needed.

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