Improvement of Ornamental Value by Seed Selection in Double-flowered Zinnias

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Abstract. In double-flowered (Dbf) zinnias (*Zinnia violacea* Cav.), seed lots inevitably contain seeds for single-flowered (Sgf) plants. A Sgf capitulum is composed of many disk florets and some ray florets with wide ovaries. A Dbf capitulum is composed of many ray florets with ovaries of various widths. Based on differences in morphology of florets that develop in Sgf and Dbf capitula and the fact that doubling is a genetically controlled trait, seeds of two cultivars of Dbf zinnias were classified into three groups by morphology of the pericarps: thin (RT) and wide (RW) seeds (achenes) produced by ray florets, and seeds (D) produced by disk florets. Plants were grown from these seeds and the ornamental value of their capitula was evaluated. Percentage of plants with Dbf capitula and the number of ray florets in a capitulum were highest for plants from RT seeds. Thus, the ornamental value of Dbf zinnias could be heightened by selecting RT seeds.

In zinnias, double-flowered (Dbf) plants yield scant amounts of pollen for successful seed production due to the small number of disk florets that are hermaphroditic, and the many ray florets that are pistillate (Miyajima, 1995; Miyajima and Nakayama, 1994). Therefore, seeds of Dbf cultivars are commercially produced by mixing them with seeds of single-flowered (Sgf) or semi-double plants to ensure a good seed yield by increasing the availability of pollen. Since the Dbf characteristic in zinnias is controlled by multiple genes (Gotoh, 1954), a high percentage of plants that have fewer ray florets segregate in the progeny. Thus, seed production of Dbf zinnias is a compromise between ornamental value and yield. In this study, I assessed the feasibility of increasing the percentage of Dbf plants by selecting seeds with a particular morphology from commercial seed lots.

My methods were based on the following facts and assumptions. Capitula of zinnias contain florets that open during a 15- to 30-d period (Miyajima and Nakayama, 1994). The degree of doubling is determined by the number of ray florets in each capitulum. Fully Dbf capitula are composed primarily of ray florets, while completely Sgf capitula are composed mostly of disk florets. In capitula, ray florets open on the first day, but may not open again. In some capitula, ray florets open day after day and such capitula become highly Dbf. In other capitula, ray florets open only on the day of anthesis; opening of disk florets follows, and

these capitula become Sgf. In a Dbf capitulum, ray florets that open early have wider petals and ovaries. Therefore, the width of ray petals and ovaries is largest in florets that open on the first day of capitulum anthesis (personal observation).

Similarly, ray petals and ovaries in Sgf capitula are wide because they open at the earliest stage. Since ovary walls become pericarps, the width of the ovaries of ray florets parallels the width of achenes. Based on these facts, the following is assumed about the conventionally produced seeds of Dbf zinnias: 1) RT seeds are produced in Dbf capitula, 2) D seeds are more likely to be produced in Sgf capitula than in Dbf capitula, and 3) the double-flowering characteristic is more pronounced in plants grown from seeds of Dbf plants than in those grown from seeds of Sgf plants. According to these assumptions, seeds produced by conventional methods were classified into RT, RW, and D seeds. The objective of this study was to evaluate if plants grown from RT seeds were ornamentally superior to plants grown from the other two types of seeds.

This study was done at the farm of the Faculty of Agriculture of Shinshu Univ. in Nagano Prefecture, Japan, at about 3°N. Seeds of the following two cultivars of zinnia were used: 'Kumamotonokagayaki', a pumila double (Takii Seed Corp., Kyoto, Japan) and 'Purple Gem', a pompon (Sakata Seed Corp., Kanagawa, Japan). Seeds of these cultivars were sown in a vermiculite medium in 1.2-L polyethylene pots. Pots were kept in a plastic film greenhouse with open sides throughout the study. Temperature and photoperiod were not controlled. The time between sunrise and sunset ranged from 13 h and 10 min to 14 h during the flowering of capitula that were observed. Seedlings were thinned to one per pot and a 14N–2.2P–5.8K liquid fertilizer (5g·L⁻¹) was applied weekly. Seedlings were planted in the field at a spacing of 0.8 m between seedlings and 1.0 m between rows.

Capitulum types of plants grown from seeds produced by crosses between Dbf, between Sgf, and between Dbf and Sgf plants. To evaluate how capitulum types of parent plants affected the F₁ progeny, seeds of 'Kumamotonokagayaki' were sown on 18 Apr. 1995, and seedlings were planted in the field on 12 June. In August, five completely single and five completely double plants were selected from the population; these plants were reciprocally cross-pollinated and bagged. Seeds were collected at maturity (≈50 d after pollination) within each of the three cross combinations [Dbf × Dbf, Sgf × Dbf (as female parent), and Sgf × Sgf], placed in envelopes and stored at 30% to 35% RH and 0 to 25 °C. Seeds were sown on 25 Apr. 1996 and seedlings were planted in the field on 20 June. In September, each plant was evaluated and classified according to the type of capitula it produced: Dbf, Sgf, or semi-double. Since the shapes of capitula varied widely among plants, capitula were classified as Sgf if less than half of the length of their receptacles were covered with ray florets when they were viewed from the side. Capitula other than Sgf were classified as semi-double if receptacles could be seen from the side; the rest were classified as Dbf. The typical shapes of the three types of capitula are shown in Fig. 1. The percentages of plants with each of the three types of capitula were

Fig. 1. Capitulum types of double-flowered zinnias classified into three groups: (A) highly double; (B) semi-double; (C) single.

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calculated. Additionally, a second or third capitulum was collected from each plant and the number of ray florets was counted. Differences in the percentages of each capitulum type among the plants grown from seeds produced by the three cross combinations were evaluated by chi-square tests, and differences in the number of ray florets in a capitulum by Scheffe's test.

Difference in maximum width of R seeds between in Dbf and Sgf capitula. Classification of the seeds into three groups was necessary to evaluate the hypothesis that plants grown from RT seeds are ornamentally superior to plants from the other two types of seeds (D seeds and RW seeds) produced in both Sgf and Dbf capitula. D seeds can easily be discriminated from R seeds by the morphology of their pericarps, while measurements are necessary to separate RT seeds from RW seeds. To classify R seeds into the two types, the following procedures were followed. In Sept. 1995, five Sgf capitula with a single layer of ray florets and five Dbf capitula that had been in the field for more than 50 d from anthesis were collected from 10 separate plants of each cultivar. After natural desiccation, the maximum widths of the pericarps or ovaries of all ray florets were measured. The maximum widths of a total of 1072 and 159 ray florets were measured for Dbf and Sgf capitula, respectively, of 'Kumamotonokagayaki', and of 627 and 283 ray florets for Dbf and Sgf capitula, respectively, of 'Purple Gem'. The widths were compared by the *t* test with Welch's correction. Histograms with 0.5 mm class intervals were made using these data and the frequency in each class was compared between the Dbf and Sgf capitula. Scales of width of the pericarps or ovaries for separation of the RT and RW seeds were determined based on the histograms.

Ornamental value of plants grown from seeds classified into three types. In Apr. 1996, newly purchased seeds of the two cultivars were easily separated into two groups, as there were clear differences between D and R seeds (Miyajima, 1996); usually D seeds were bright ivory and R seeds were dark brown. The surface of D seeds was smooth, while that of R seeds was rough. Each R seed had a ridge on the surface of its pericarp. Based on the results of distribution of the width of pericarps or ovaries of ray florets, R seeds of 'Kumamotonokagayaki' were separated into two groups with widths ≥ 3.0 mm (RW seeds) and < 3.0 mm (RT seeds). For 'Purple Gem', pericarp widths were ≥ 2.5 mm or < 2.5 mm. Seeds of the two cultivars were sown on 18 Apr. 1996. On 20 June, seedlings were planted in the field in a completely randomized design. In Sept., a matured second or third capitulum was collected from each plant. The numbers of capitula collected were 89, 97, and 60 for the plants grown from D, RW, and RT seeds, respectively, for 'Kumamotonokagayaki', and 67, 89, and 57, respectively, for 'Purple Gem'. These capitula were classified into three categories according to their morphology: Dbf, Sgf, or semi-double. The number of ray florets in each capitulum was counted. In each culti-

var, the percentages of each capitulum type were compared among the plants from the three types of seed by chi-square test, and the numbers of ray florets in a capitulum were compared by Scheffe's test.

Results and Discussion

Capitulum types of plants grown from seeds produced by crosses between Dbf, between Sgf, and between Dbf and Sgf plants. All plants grown from seeds produced by crossing two Dbf plants had A-type capitula (Table 1). More than half of the plants from seeds produced by crossing two Sgf plants had C-type capitula. Some plants from seeds produced by Sgf $\times$ Sgf crosses had A-type capitula. More than half of the plants from seeds produced by crossing Sgf with Dbf plants had A-type capitula, while 16% had C-type capitula. A high percentage of plants with B-type capitula were obtained from seeds produced by Sgf $\times$ Sgf and Sgf $\times$ Dbf crosses. Thus, the Dbf characteristic in parent plants directly affected the characteristic in their F_1 progeny. From these results, I conclude that seeds obtained from Dbf capitula are more likely to produce plants with higher ornamental value than seeds obtained from Sgf capitula.

Difference in maximum width of R seeds from Dbf vs. Sgf capitula. The maximum widths of pericarps or ovaries of ray florets were significantly different for Sgf vs. Dbf

capitula in both cultivars ($P < 0.01$) (Fig. 2). For Sgf capitula of 'Kumamotonokagayaki', ray florets had pericarps or ovaries that were > 2.0 mm. Modal values were 3.25 and 2.75 mm for the Sgf and Dbf capitula, respectively. Based on Fig. 2, 3.0 mm was selected as the standard to separate R seeds of 'Kumamotonokagayaki'. For 'Purple Gem', distribution ranges did not differ between the Sgf and Dbf capitula. Modal values were 2.75 and 1.75 mm for the Sgf and Dbf capitula, respectively, and a value of 2.5 mm was used as the standard to separate R seeds in this cultivar.

RW seeds would be more effectively excluded if 2.5 and 2.0 mm were used as standards for separation for 'Kumamotonokagayaki' and 'Purple Gem', respectively. However, the quantity of RW seeds that would be discarded if this method were used would be large using these standards. Therefore, 3.0 mm and 2.5 mm were recommended as the best standards for separation and were used in this study.

Ornamental value of plants grown from seeds classified into three types. For 'Kumamotonokagayaki', the percentage of plants with A-type capitula was twice as great for plants grown from R seeds than for those from D seeds (Table 2). The percentage of plants with A-type capitula was slightly higher for plants from RT seeds than for those from RW seeds. Ten percent or fewer plants from R seeds produced C-type capitula, while 28% of

Table 1. Distribution of capitulum type among zinnia plants grown from seeds produced by crossing single- (Sgf) and double-flowered (Dbf) plants of 'Kumamotonokagayaki'.

Cross combination ^y	Capitulum type ^z (%)		
	A	B	C
Dbf $\times$ Dbf	100	0	0
Dbf $\times$ Sgf	59	25	16
Sgf $\times$ Sgf	7	33	60

^zSee Fig. 1. Differences between cross combinations are significant at $P \leq 0.01$ by the chi-square test for independence.

^yDbf $\times$ Dbf, Dbf $\times$ Sgf, and Sgf $\times$ Sgf denote that seeds were produced by crosses between Dbf plants, between Dbf and Sgf plants, and between Sgf plants, respectively.

Fig. 2. Distribution by width of seeds produced by ray florets in double- and single-flowered zinnia capitula. White and black bars denote percentage of each class in the double- and single-flowered capitula, respectively.

the plants grown from D seeds had C-type capitula. In 'Purple Gem', plants with A-type capitula were greatest for plants grown from RT seeds. Also, the percentage of plants with each type of capitulum differed significantly between plants grown from R vs. D seeds ($P < 0.01$ by the chi-square test for independence). Plants with Sgf capitula comprised 55% of the plants grown from D seeds. In both cultivars, the differences in percentages of each type of capitulum between plants from RT and RW seeds were not statistically significant when compared by chi-square test.

For 'Kumamotonokagayaki', the number of ray florets in a capitulum was greatest on plants grown from RT seeds and fewest on those grown from D seeds (Table 3). For 'Purple Gem', the number of ray florets in a capitulum differed between plants grown from RT and D seeds. Thus, using RT seeds could improve the ornamental value of plants. Unlike pumila-double cultivars, plants with completely Sgf capitula are rarely found in pompon cultivars (personal observation). In addition, the total number of florets in a capitulum is fewer in 'Purple Gem' than in 'Kumamotonokagayaki'. The difference between 'Kumamotonokagayaki' and 'Purple Gem' in the effects of seed selection on ornamental value may be attributed to these factors.

In both cultivars, percentage of capitulum type did not differ between plants from RT vs. RW seeds by chi-square test, but the number of ray florets differed significantly in 'Kumamotonokagayaki'. Actually, shapes of capitula vary widely depending on the number of ray florets. Each of the capitulum types defined in this experiment, especially double and semi-double types, included many capitulum shapes. Therefore, classification into only three types is approximate. The best classification method for capitulum shape should be developed based on ornamental value.

A method to increase the yield of seeds genetically capable of producing Dbf plants is to collect seeds from only Dbf plants at harvest. However, harvesting machines cannot select Dbf capitula. Instruction is necessary for workers in the standards of capitulum type to be harvested by hand. In addition, judging which capitula to harvest and which to discard

Table 2. Distribution of capitulum type in zinnia plants of two cultivars grown from seeds of three types.

Seed type ^a	Capitulum type ^c (%)		
	A	B	C
<i>Kumamotonokagayaki</i>			
D	31	41	28
RW	62	28	10
RT	67	24	9
Significance		**	
<i>Purple Gem</i>			
D	21	24	55
RW	46	19	35
RT	54	27	19
Significance		**	

^aSee Fig. 1.

^bD: seeds produced by disk florets. RW: wide seeds produced by ray florets (≥ 3.0 mm and ≥ 2.5 mm for 'Kumamotonokagayaki' and 'Purple Gem', respectively). RT: thin seeds produced by ray florets (< 3 mm and < 2.5 mm for 'Kumamotonokagayaki' and 'Purple Gem', respectively).

^cThe percentages are significantly different among seed types by the chi-square test for independence ($P < 0.01$).

Table 3. Width of pericarp and number of ray florets per capitulum of zinnia plants grown from seeds produced by thin ray (RT), wide ray (RW), and disk (D) florets.

Cultivar	Seed type	Width of pericarp (mm)	No. ray florets
Kumamotonokagayaki	RT	< 3.0	350 a ^c
	RW	≥ 3.0	258 b
	D	---	216 c
Purple Gem	RT	< 2.5	147 a
	RW	≥ 2.5	135 ab
	D	---	114 b

^cMean separation by Scheffe's test ($P < 0.05$).

requires much time and labor, especially after senescence of the ray petals. Also, the selection standard varies for individual workers because a population of zinnias contains plants with various types of capitula in addition to those that are completely double or completely single. Subjective selection by individual workers is inevitable; thus, harvest and selection of preferred types of capitula is not recommended. Classification of the harvested seeds is more practical. For the practical use of the seed-selection method, development of machines for seed classification with image-analyzing systems is necessary.

The seed selection method can also be used for seed production to save labor and space. For seed production of Dbf zinnias, some degree of the roguing of plants with Sgf capitula is necessary to prevent an increase in

Sgf seeds. However, this requires much labor and reduces seed yields. Reduction in seed yields can be minimized by using RT seeds, which contain more seeds that produce Dbf plants than do nonselected seeds.

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