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# An Attempt of Crossbreeding in Garlic

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## Introduction

Garlic (*Allium sativum* L.) is one of the representative vegetatively-propagated crops, even though the viable seeds have been obtained from some fertile clones[1, 4, 6, 12, 15]. As a vegetatively-propagated crop, garlic is reproduced exclusively by cloves in the bulbs and by bulbils in the inflorescences. And like other crops of this kind it has common advantages, such as the maintenance of excellent characters obtained by mutation. However, it has also a lot of disadvantages. The most disadvantageous point is the fact that it is impossible for us to carry out crossbreeding, which makes the convenient improvement of this crop almost impossible. Some researchers attempted to resolve this problem and got a few progresses, such as the researches about the causes of sterility[2, 10, 11, 13, 14, 17], searches of fertile clones[3, 5, 6], seed production[4, 15], seed germination[1, 16], and the culture of garlic seedlings[16].

A large number of fertile clones were collected in 1994 around the Tien Shan Mountains of the Central Asia, which was identified as the primary center of origin of garlic[6]. And in this study, self- and open-pollination were carried out to obtain seeds from these clones, and crossing was also carried out among them. In short, the potential utilization of these fertile clones in garlic breeding was studied.

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## Materials and Methods

*Plant materials*

Garlic clones collected in the Central Asia[3, 6] (Table 1) had been grown in Kagoshima University since the collections made twice in 1983 and 1994. The detailed information on the collected clones is shown by Etoh[3] and Hong and Etoh[6]. The pollination was carried out in those fertile clones in the summer seasons of 1995, 1996, 1997, and 1998. Moreover, garlic seedlings (Table 2) previously obtained from those fertile clones were also used in this study. F clones were the progenies obtained by open pollination of the original clones collected in Soviet Central Asia in 1983[4]. $F_1$ and $F_4$ clones were the seedlings of the first and the fourth generations obtained by open-pollination among the original clones. Self- and cross-pollination among these clones were attempted besides open-pollination, as shown in the followings.

Table 1. Central Asian garlic clones used for the trials of seed production

| Clone No. | Origin | Pollen fertility (%) | Clone No. | Origin | Pollen fertility (%) |
|---|---|---|---|---|---|
| No. 130 | Russia | 80.8 | No. 176 | Russia | 56.7 |
| No. 184 | Uzbekistan | 90.0 | No. 190 | Uzbekistan | 80.4 |
| No. 191 | Uzbekistan | 81.5 | No. 192 | Uzbekistan | 84.3 |
| No. 198 | Kirghizstan | 91.4 | No. 201 | Kirghizstan | 19.6 |
| No. 364 | China | 7.5 | No. 365 | China | 4.0 |
| No. 366 | China | 5.7 | No. 367 | Kazakhstan | 6.8 |
| No. 368 | Kazakhstan | 76.5 | No. 369 | Kazakhstan | 4.9 |
| No. 370 | Kazakhstan | 60.0 | No. 371 | Kazakhstan | 38.7 |
| No. 372 | Kazakhstan | 58.2 | No. 373 | Kazakhstan | 43.5 |
| No. 374 | Kazakhstan | 31.9 | No. 375-1 | Kazakhstan | 29.7 |
| No. 375-2 | Kazakhstan | 7.6 | No. 376 | Kazakhstan | - |
| No. 377 | Kazakhstan | 14.6 | No. 378 | Kirghizstan | - |
| No. 379 | Kirghizstan | 0.0 | No. 380 | Kirghizstan | 6.3 |
| No. 381 | Kirghizstan | 73.6 | No. 381 | Kirghizstan | 66.6 |
| No. 382 | Kirghizstan | 66.6 | No. 383 | Kirghizstan | - |
| No. 384 | Kirghizstan | 0.0 | No. 385 | Kirghizstan | 67.6 |
| No. 386 | Kirghizstan | 79.0 | No. 387 | Kirghizstan | 0.0 |
| No. 388 | Kirghizstan | 78.7 | No. 389 | Kirghizstan | 63.1 |
| No. 390-1 | Kirghizstan | 85.1 | No. 390-2 | Kirghizstan | 0.0 |
| No. 391-1 | Kirghizstan | 86.8 | No. 391-2 | Kirghizstan | - |
| No. 392 | Kirghizstan | 75.2 | No. 393-1 | Kirghizstan | 85.6 |
| No. 392-2 | Kirghizstan | 0.0 | No. 394 | Kirghizstan | 4.7 |
| No. 395-1 | Kirghizstan | 76.6 | No. 395-2 | Kirghizstan | 0.0 |
| No. 396 | China | 70.0 | No. 397 | China | 19.2 |
| No. 398 | China | 38.6 | | | |

*Trials in* 1995 *and* 1996

The cloves of all the fertile original clones (Table 1) and seedlings (Table 2) were planted at Kagoshima University in the autumn of 1994 and 1995. In the next spring the growing plants were covered by plastic sheet to protect them from rain till the seed harvest. Owing to the hot weather during summer in Kagoshima, the plants were shaded against the sun shine with cheese-cloth from early June to harvest.

Three plants of each fertile original clone (Table 1) were used for self-pollination, and some others were used for open-pollination. Spathes of these clones were opened by hands when bulbils filled the spathe completely. Then, the bulbils of the inflorescence were removed, and the inflorescences for self-pollination were covered by paper bags before anthesis. All bulbils and most of the flower buds were removed from the inflorescences in those female parent clones for cross-pollination (Table 3), and then stamens were also removed. Pollination was carried out by hand in the morning as soon as flowering began, and it was repeated at least three times in each inflorescence during the flowering period. The paper bags were removed when ovaries began to develop. Seeds were harvested when the plant got withered.

Table 2. Garlic seedlings used for the trials of seed production

| | | | | |
|---|---|---|---|---|
| F-19 | F-21 | F-47 | F-91 | F-111 |
| F-112 | F-115 | F-116 | F-117 | F-123 |
| F-126 | F-133 | F-138 | F-141 | F-145 |
| F-146 | F-147 | F-150 | F-152 | F-153 |
| F-163 | F-167 | F-177 | F-184 | F-187 |
| F-189 | F-199 | F-214 | F-215 | F-223 |
| F-227 | F-230 | F-254 | F-262 | F-265 |
| F-278 | F-294 | F-303 | F-308 | F-309 |
| F-310 | F-316 | F-321 | F-323 | F-333 |
| F-346 | F-364 | F-365 | F-367 | F-369 |
| F-370 | F-372 | F-376 | F-379 | F-413 |
| F-422 | F-424 | F-431 | F-436 | F-437 |
| F-443 | F-452 | F-446 | F-466 | F-476 |
| F-494 | F-495 | F-502 | F-517 | F-518 |
| F-519 | F-520 | F-527 | F-528 | F-529 |
| $F_1$-137 | $F_1$-141 | $F_1$-143 | $F_1$-144 | $F_1$-152-5 |
| $F_1$-152-6 | $F_1$-178 | $F_1$-178-1 | $F_1$-200-8 | $F_1$-200-14 |
| $F_1$-200-16 | $F_1$-200-17 | $F_1$-200-21 | $F_1$-200-23 | $F_1$-200-34 |
| $F_1$-200-37 | $F_1$-200-40 | $F_1$-200-46 | $F_1$-200-55 | $F_1$-200-60 |
| $F_1$-200-62 | $F_1$-200-74 | $F_1$-200-92 | $F_1$-200-134 | $F_1$-223 |
| $F_4$-401 | $F_4$-402 | $F_4$-403 | $F_4$-404 | $F_4$-405 |
| $F_4$-406 | $F_4$-407 | $F_4$-408 | $F_4$-409 | $F_4$-410 |
| $F_4$-411 | $F_4$-412 | $F_4$-413 | $F_4$-414 | $F_4$-415 |
| $F_4$-416 | $F_4$-417 | $F_4$-418 | $F_4$-419 | $F_4$-420 |
| $F_4$-421 | $F_4$-422 | $F_4$-423 | $F_4$-424 | |

In spite of pollination, all the plants were blown down by the typhoons attacking one after another in the summer of 1996. The first typhoon attacked Kagoshima on July 18, 1996, about 10 days after pollination. Therefore, only few seeds were obtained, though the plants grew very well in this growing season. Moreover, all the labels for the information of pollination were blown away by those typhoons, and the detection of pollination record was impossible in 1996.

*Trial in* 1997

To protect plants from typhoons, garlic clones were planted both in open field and at a glass house in the autumn of 1996. Three plants were planted in a pot of 18 cm in diameter (Table 4), and then they were grown in a glass house. The way of pollination was as the same as described above. Artificial pollination was carried out in the summer of 1997. The plants did not grow so well in the field this year for some reasons.

*Trial in* 1998

Planting was delayed to late-autumn in 1997 because of changing the fields. It was one month later than usual. Growth was also delayed in this cycle. Pollination could not be

carried out in those fertile clones. Cross-pollination was carried out only in several plants of F, $F_1$ and $F_1$ clones (Table 5).

Table 3. Combinations of cross-pollination and the number of pollinated flowers (1995)

| Combination (♀ x ♂) | No. of pollinated flowers | Combination (♀ x ♂) | No. of pollinated flowers |
|---|---|---|---|
| No. 368 x No. 370 | 17 | No. 368 x No. 381 | 18 |
| No. 368 x No. 382 | 15 | No. 368 x No. 388 | 19 |
| No. 368 x No. 389 | 12 | No. 268 x No. 392 | 15 |
| No. 368 x No. 398 | 15 | No. 370 x No. 368 | 9 |
| No. 370 x No. 373 | 10 | No. 370 x No. 390-1 | 11 |
| No. 370 x No. 391 | 12 | No. 371 x No. 386 | 10 |
| No. 371 x No. 389 | 10 | No. 372 x No. 368 | 10 |
| No. 372 x No. 375 | 12 | No. 372 x No. 388 | 13 |
| No. 373 x No. 370 | 12 | No. 373 x No. 382 | 11 |
| No. 373 x No. 392 | 13 | No. 375-1 x No. 381 | 11 |
| No. 375-1 x No. 391 | 16 | No. 379 x No. 388 | 10 |
| No. 379 x No. 391 | 16 | No. 381 x No. 372 | 14 |
| No. 381 x No. 386 | 16 | No. 381 x No. 396 | 13 |
| No. 382 x No. 381 | 15 | No. 382 x No. 392 | 15 |
| No. 382 x No. 393-1 | 13 | No. 385 x No. 370 | 11 |
| No. 385 x No. 388 | 10 | No. 385 x No. 393-1 | 13 |
| No. 386 x No. 373 | 16 | No. 386 x No. 392 | 17 |
| No. 386 x No. 396 | 8 | No. 388 x No. 370 | 13 |
| No. 388 x No. 371 | 16 | No. 388 x No. 390-1 | 14 |
| No. 389 x No. 370 | 15 | No. 389 x No. 382 | 12 |
| No. 389 x No. 392 | 23 | No. 390-1 x No. 393-1 | 10 |
| No. 391-1 x No. 70 | 10 | No. 391-1 x No. 389 | 11 |
| No. 391-1 x No. 396 | 15 | No. 392 x No. 368 | 15 |
| No. 392 x No. 373 | 15 | No. 392 x No. 381 | 13 |
| No. 392 x No. 390-1 | 8 | No. 392 x No. 370 | 14 |
| No. 392 x No. 373 | 12 | No. 392 x No. 381 | 11 |
| No. 393-1 x No. 370 | 14 | No. 393-1 x No. 373 | 12 |
| No. 393-1 x No. 381 | 13 | No. 393-2 x No. 389 | 12 |
| No. 393-2 x No. 381 | 12 | No. 393-2 x No. 391 | 10 |
| No. 395 x No. 372 | 10 | No. 395 x No. 382 | 12 |
| No. 395 x No. 385 | 16 | No. 395 x No. 388 | 9 |
| No. 395 x No. 392 | 11 | No. 396 x No. 368 | 8 |
| No. 396 x No. 373 | 12 | No. 396 x No. 388 | 15 |
| No. 396 x No. 392 | 12 | No. 398 x No. 370 | 13 |
| No. 396 x No. 382 | 11 | No. 398 x No. 389 | 13 |
| No. 398 x No. 390-1 | 14 | No. 398 x No. 392 | 14 |

Table 4. Clones grown in pots for the trial of seed production in the growing season of 1996-1997

| | | | |
|---|---|---|---|
| No. 130 | No. 176 | No. 184 | No. 190 |
| No. 191 | No. 192 | No. 198 | No. 200 |
| No. 368 | No. 370 | No. 371 | No. 372 |
| No. 373 | No. 375-1 | No. 379 | No. 381 |
| No. 382 | No. 382 | No. 383 | No. 385 |
| No. 386 | No. 388 | No. 389 | No. 390-1 |
| No. 390-2 | No. 391-1 | No. 392 | No. 393-1 |
| No. 393-2 | No. 395-1 | No. 395-2 | No. 396 |
| No. 398 | F-47 | F-91 | F-123 |
| F-138 | F-214 | F-294 | F-303 |
| F-424 | F-437 | F-494 | $F_1$-137 |
| $F_1$-152-5 | $F_1$-152-6 | $F_1$-200-16 | $F_1$-200-23 |
| $F_1$-200-37 | $F_1$-200-40 | $F_1$-200-46 | $F_1$-223 |
| $F_4$-401 | $F_4$-402 | $F_4$-407 | $F_4$-408 |
| $F_4$-409 | $F_4$-415 | $F_4$-418 | $F_4$-420 |
| $F_4$-424 | | | |

Table 5. Combinations of cross-pollination in 1998

| Combination (♀ x ♂) | Combination (♀ x ♂) | Combination (♀ x ♂) |
|---|---|---|
| F-138 x $F_4$-417 | F-167 x No. 395 | F-177 x F-123 |
| F-177 x $F_4$-417 | F-199 x No. 395, F-177 | F-199 x No. 395, $F_4$-417 |
| F-199 x $F_4$-417 | $F_4$-407 x F-177 | $F_4$-407 x F-199 |
| $F_4$-407 x $F_1$-143 | $F_4$-407 x $F_4$-417 | $F_4$-407 x $F_4$-418, $F_4$-417 |
| $F_4$-407 x $F_4$-423 | $F_4$-407 x $F_4$-423, $F_1$-143 | $F_4$-418 x $F_4$-417 |
| $F_4$-420 x F-177 | $F_4$-420 x $F_4$-417 | $F_4$-422 x $F_4$-423 |
| $F_4$-423 x F-177 | $F_4$-423 x $F_4$-417 | |

## Results

Seeds were obtained by self- and open-pollination in the respective years (Tables 6 to 11), but only small amounts of seeds were harvested. Among the harvested seeds, big and substantial seeds were considered to be mature seeds. On the contrary, small, flattened, or shriveled seeds were considered to be immature ones. High percentages of seeds were immature in those trial years.

In 1995, one plant of No. 398 produced the largest number of seeds, 103, but no one of those was mature. All three plants of Nos. 372, 388, 391-1, No. 393-1, and 395 produced seeds, however the numbers were not great, counting less than 40 per plant (Table 6). Only concerning F clones, open-pollination was carried out in 1995, and the largest number of seeds, 142, were obtained from one plant of F-214. Almost all of the F clones produced only a small amount

Table 6. Seed production by self-pollination in 1995

| Clone No. | No. of florets per inflorescence | Number of seeds harvested | | |
|---|---|---|---|---|
| | | Plant No. 1 | Plant No. 2 | Plant No. 3 |
| No. 370 | 230.7 | 3(1)[1] | 21(7) | 0 |
| No. 371 | 165.0 | 14 | 2(2) | 0 |
| No. 372 | 130.7 | 1(1) | 34(3) | 10(2) |
| No. 373 | 147.0 | 17 | 0 | 0 |
| No. 381 | 177.3 | 1 | 0 | 0 |
| No. 382 | 150.3 | 3 | 0 | 0 |
| No. 385 | 139.7 | 21 | 0 | 0 |
| No. 386 | 192.7 | 4(2) | 0 | 0 |
| No. 388 | 170.3 | 2(1) | 4(2) | 10(2) |
| No. 389 | 127.3 | 24(1) | 0 | 0 |
| No. 390-1 | 191.7 | 8 | 2 | 0 |
| No. 391-1 | 201.7 | 4 | 4(2) | 3(2) |
| No. 392 | 154.3 | 4 | 0 | 0 |
| No. 393-1 | 191.7 | 3 | 15(6) | 4 |
| No. 395 | 171.0 | 9 | 2 | 4 |
| No. 398 | 123.7 | 103 | 0 | 0 |

[1]: Mature seeds

of seeds (Table 7). In case of the crossing combinations, 11 pollinated flowers of No. 385 (♀) x No. 370 (♂) produced 39 seeds (Table 8). Comparing with self- and open-pollination, greater number of seeds were obtained per flower.

In 1996, seed production was made to be failed because of typhoons. Garlic grew very well this year, but not so many seeds were obtained (Table 9). Nos. 370, 385, 388, and 390-1 produced seeds in both two years. No. 130 produced the largest number of seeds. Nos. 184, 190, 192, and 198 collected in 1983 also produced seeds after 12 years of their collection. High percentages of those seeds were not mature.

In 1997, garlic grew very weakly in the field. In order to maintain the clones, all the clones in the field were harvested before flowering. Artificial pollination was carried out onto those clones planted in the glass house (Table 10). During the blooming period, it rained all the time, and anthers did not dehisce normally probably because of humid air. Seeds were not obtained from the original clones, and the seeds obtained from $F_1$, $F_{11}$, and $F_4$ were small and shriveled.

In the autumn of 1997, garlic cloves were planted in November, more than one month later than usual because of changing of fields. Low temperature and long rain during the germinating period had bad effect on germination. Long rain in May of 1998 gave garlic only poor leaf growth and scanty flower-stalk development. Flower bud formation was not so good this year, and only a small amount of seeds were obtained by cross pollination among $F_1$ and $F_4$ clones (Table 12).

Table 7. Seed production by open-pollination in 1995

| Clone No. | No. of seeds harvested | Clone No. | No. of seeds harvested |
|---|---|---|---|
| No. 368 | 2 | No. 368 | 11 |
| No. 370 | 11 | No. 373 | 13 |
| No. 373 | 45 | No. 375 | 6(1) |
| No. 381 | 17 | No. 388 | 18 |
| No. 388 | 133 | No. 392 | 2 |
| No. 394 | 47 | F-47 | 16 |
| F-91 | 21 | F-111 | 14 |
| F-123 | 12 | F-126 | 18 |
| F-138 | 66 | F-146 | 8 |
| F-147 | 8 | F-150 | 2 |
| F-153 | 23 | F-177 | 16 |
| F-178 | 29 | F-184 | 13 |
| F-199 | 36 | F-214 | 142 |
| F-254 | 22 | F-262 | 48 |
| F-278 | 7 | F-294 | 10 |
| F-303 | 54 | F-316 | 18 |
| F-333 | 25 | F-369 | 13 |
| F-370 | 14 | F-413 | 39 |
| F-424 | 47 | F-431 | 5 |
| F-437 | 24 | F-437 | 15 |
| F-437 | 14 | F-441 | 2 |
| F-443 | 27 | F-443 | 11 |
| F-452 | 1 | F-494 | 5 |
| F-494 | 10 | F-494 | 24 |
| F-519 | 18 | F-519 | 22 |
| F-519 | 10 | | |

Table 8. Seed production by cross-pollination in 1995

| Crossing combination (♀ x ♂) | No. of seeds/ No. of florets pollinated | Crossing combination (♀ x ♂) | No. of seeds/ No. of florets pollinated |
|---|---|---|---|
| No. 368 x No. 388 | 13/15 | No. 368 x No. 392 | 22/15 |
| No. 370 x No. 373 | 4/10 | No. 371 x No. 386 | 8/10 |
| No. 373 x No. 370 | 26/12 | No. 373 x No. 382 | 11/11 |
| No. 373 x No. 392 | 26/13 | No. 385 x No. 370 | 39/11 |
| No. 385 x No. 393-1 | 30/13 | No. 386 x No. 373 | 26/16 |
| No. 386 x No. 396 | 20/ 8 | No. 388 x No. 371 | 1/16 |
| No. 391-1 x No. 389 | 3/11 | No. 393-1 x No. 381 | 4/13 |
| No. 393-1 x No. 389 | 8/12 | No. 395 x No. 392 | 3/11 |
| No. 396 x No. 368 | 10/ 8 | No. 398 x No. 390-1 | 13/14 |

* : A floret has six ovules.

Table 9. Seed production in 1996[1)]

| Clone No. | No. of seeds harvested | Clone No. | No. of seeds harvested |
|---|---|---|---|
| No. 130 | 146(6)[2)] | No. 176 | 113(2) |
| No. 184 | 16 | No. 190 | 7 |
| No. 191 | 34 | No. 192 | 12 |
| No. 198 | 34 | No. 368 | 14(1) |
| No. 370 | 7 | No. 375-1 | 6 |
| No. 385 | 11(1) | No. 388 | 62(1) |
| No. 390-1 | 81 | F-138 | 1 |
| F-141 | 9(6) | F-152 | 6 |
| F-214 | 1 | F-214 | 3 |
| F-294 | 14 | $F_1$-200-23 | 12(4) |
| $F_1$-200-40 | 10 | $F_1$-200-40 | 7 |
| $F_1$-200-40 | 3 | $F_1$-200-46 | 5 |
| $F_4$-401 | 3 | $F_4$-408 | 8(1) |
| $F_4$-411 | 7(4) | $F_4$-415 | 62(10) |
| $F_4$-418 | 8 | $F_4$-418 | 1 |
| $F_4$-418 | 1 | $F_2$-152-12 | 3(2) |

1): The pollination methods are unclear because typhoons destroyed all the recorded labels.

2): Mature seeds

Table 10. Seed production by self-pollination in 1997

| Clone No. | No. of florets per inflorescence | Plant No. 1 | Plant No. 2 | Plant No. 3 |
|---|---|---|---|---|
| F-91 | 97.3 | 140 | 56 | 268 |
| F-294 | 121.0 | 9 | 0 | 0 |
| F-437 | 131.0 | 1 | 0 | 0 |
| $F_1$-152-6 | 127.0 | 0 | 1 | 0 |
| $F_1$-200-37 | 185.0 | 57 | 230 | 58 |
| $F_4$-401 | 182.0 | 11(4)[1)] | 0 | 22(3) |
| $F_4$-408 | 117.0 | 23 | 0 | 0 |
| $F_4$-409 | 115.0 | 2 | 0 | 0 |
| $F_4$-415 | 127.0 | 20(3) | 22(3) | 13(6) |
| $F_4$-418 | 87.0 | 28 | 0 | 0 |
| $F_4$-420 | 116.0 | 76 | 25 | 0 |

1): Mature seeds

Table 11. Seed production by cross-pollination in 1998

| Crossing combination (♀ x ♂) | No. of seeds/ No. of florets pollinated | Crossing combination (♀ x ♂) | No. of seeds/ No. of florets pollinated |
|---|---|---|---|
| F-138 x $F_4$-417 | 12/178 | F-167 x No. 395 | 3/ 57 |
| F-177 x F-123 | 12/ 93 | F-177 x $F_4$-417 | 36/153 |
| F-177 x $F_4$-417 | 43/173 | F-177 x $F_4$-417 | 44/129 |
| F-199 x No. 395 F-177 | 15/ 97 | F199 x No.395 $F_4$-417 | 26/107 |
| F-199 x $F_4$-417 | 13/ 94 | $F_4$-407 x F-177 | 31/267 |
| $F_4$-407 x F-177 | 9/187 | $F_4$-407 x F-199 | 32/254 |
| $F_4$-407 x $F_1$-143 | 17/311 | $F_4$-407 x $F_1$-143 | 26/273 |
| $F_4$-407 x $F_4$-418 | 49/237 | $F_4$-407 x $F_4$-418 $F_4$-417 | 55/194 |
| $F_4$-420 x $F_4$-417 | 17/127 | $F_4$-424 x $F_4$-417 | 12/ 87 |

* : A floret has six ovules.

## Discussion

From 1995 to 1998, garlic clones collected in the Central Asia produced germinable seeds (Tables 6 to 11), though most of them were not mature. Moreover, high percentages of the harvested seeds were empty seeds. Seed germination was attempted, but seedlings died when they were transferred to soil, or after reaching the 2-3 leaf stage. The results obtained from these 4 trials were far from the intended research purpose.

The first success of seed production in garlic was reported by Etoh et al.[4] More than 3,000 seeds were obtained by open-pollination from fertile garlic clones collected in the Central Asia in 1983. And further, seedlings of garlic were obtained from these seeds, and those seedlings became F clones, which were used in the present study. One suggestion was presented by Etoh et al.[4] that seed production and seed germination varied with the clones, and the same result was obtained also in this study. In the first trial year, No. 398 produced the largest number of seeds. And during these 4 years, no seed was produced from Nos. 362, 364, 365, 366, 367, 369, 375-2 376, 378, 380, 382, 383, 385, 387, 390-2, 391-2, 393-2, 394, and 395-2, regardless of pollination methods. Nos. 390-2, 391-2, 393-2, and 395-2 shed yellow pollen grains, which were sterile. Among the clones which did not produce seeds, Nos. 382 and 383 showed high pollen fertilities. Although they did not succeed in seed formation, ovary development after pollination was observed in these clones. There might be several reasons, such as no ability to produce seeds, unsuitable environmental conditions, or lack of nutrient.

There was no marked difference between self- and open-pollination in the present study. Besides the present trials, large number of seeds, over 200 per plant, were obtained by open-pollination, using the same original clones as those used at the present trials[7]. By self-pollination of the present trial, 268 seeds were obtained from a plant of F-91 in 1997, though the seeds were immature. Therefore, it become necessary to conduct more detailed research on self-incompatibility.

From the results of seed production in the four trial years, the effect of environmental conditions may be considered to be an important factor. Pooler and Simon[15] reported that 63 germinable seeds from 11 different garlic clones were obtained during 5 years, and suggested that when flowers were exposed to intense sunlight and heat or to the prolonged temperature below 18.3 ℃, seed set was greatly reduced. From the same original clones as those collected in the Central Asia in 1983, a large number of seeds, more than 50,000 were obtained in 1994 successfully at a town in the northern Japan[10] which is situated at nearly latitude 41°N. This latitude is similar to the latitude of the north side of Tien Shan Mountains. Moreover, a few kg of garlic seeds were obtained by an American seed company[9] in California. Garlic originated in the Central Asia having long and very cold winter, besides hot and dry flowering season with very long day-length. On the contrary, Kagoshima has warm winter and also hot and humid or rainy flowering season with the day-length which is much shorter than that of the north side of the Tien Shan Mountains. Besides, night temperature is extremely high during summer, and the plants from the north exhaust. Their bulbs do not grow well as in the native area. These unsuitable environmental conditions might have resulted in low seed production in the present trials.

Among the F, $F_1$ and $F_4$ clones, seed productivities also varied with clones. It was suggested that the progenies of garlic had the same seed productive character as the original fertile clones. A large number of these clones produced seeds in 1995, and in the following years these clones produced seeds even when original fertile clones did not produce seeds. Antheses of these clones, especially $F_1$ and $F_4$ clones, were more than one week earlier than original fertile clones. It might offer a little longer time to develop seed. In addition to this, plants from seeds might be stronger than those plants reproduced by vegetative way.

Seeds were produced also by cross pollination, and the purpose of the trial was to search either appropriate female parent clones or male parent clones. In 1995, the number of seeds per cross-pollinated flower was higher than those of self- and open-pollinated ones, but this was not observed in 1997. There were not so many florets left remaining after most of the flowers were removed from the individual inflorescence for trial in 1995. Therefore, the nutrient was allowed to be concentrated to this small number of flowers, which produced more seeds in number. But in 1997, no flower was removed, and fewer seeds were produced by cross-pollination. This might have caused the difference in seed production between the two trial years. Neither good material line nor paternal line was identified in this study.

Although the results were far from the intended purpose, viable seeds were really produced from the original clones collected in the Central Asia and from their progenies. The seed production in this study was not so successful as that in case of Etoh et al.[4] According to their report[4], it was proved that garlic could grow and develop from seeds to full mature bulbs with scapes within one year. The clones which were collected in 1994 and used in this study had the same high pollen fertility as those collected in 1983. Therefore, it can be expected to utilize them in garlic breeding, by adopting several ways such as avoiding unsuitable climate, tightening up the material management from pre-flowering period to seed-mature stage for better seed development, or searching the most proper way of pollination.

## Summary

From 1995 to 1998, garlic seeds were produced by self-, open-, and cross-pollination in

those fertile clones collected around the Tien Shan Mountains in 1994 and in the seedlings of the progenies of the original clones collected in the Central Asia in 1983. In 1995, a large number of seeds, counting 103, were produced from one plant of No. 398, but none of those was mature. On the other hand, small numbers of seeds, counting less than 40 per plant, were obtained from other clones. Open-pollination was also carried out to F clones in the same year, and the largest number of 143 seeds were obtained from F-214. Comparing with self- and open-pollination, a great number of seeds per flower were obtained from the combination of No. 385 (♀)x No. 370 (♂), counting 39 seeds from 11 pollinated flowers. So many seeds were not obtained in 1996, because of the failure of seed production occasioned by typhoons. A long rainy season during the blooming period prevented anthers from dehiscing normally, resulting in the comparatively poor seed production in 1997. Long rain in May of 1998 gave garlic poor leaf growth and scanty flower-stalk development. Flower formation was not so good this year, with only a small amount of seeds obtained by cross-pollination among F and $F_1$ clones. After all, the numbers of the produced seeds were not great, and most of them were immature. Although the results were far from the intended purpose, these clones will be useful in garlic breeding, by adopting several ways such as avoiding the unsuitable climate, tightening up the material management from flowering period to seed-mature stage for better seed development, or searching the most proper way of pollination.

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