Growth, Yield and Quality of Bird-Resistant Sunflower Cultivars Found in Genetic Resources

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Abstract: We examined 50 cultivars of sunflower (Helianthus annuus L.) for their resistance to birds in a field experiment to find parental plants for breeding. Two cultivars, Armarvirski3497 (from Russia) and Line-41 (from Myanmar), had bird-resistant characteristics. The laboratory bird feeding test indicated that the factors associated with bird resistance were globular seed shape and heavy seed coat, because the main bird feeding on sunflower, oriental greenfinch Carduelis sinica, is relatively small and have difficulty pecking large and globular seeds. Although the two cultivars had unfavorable characters such as low tolerance to lodging and late maturity, the oil contents of their seeds was not significantly lower than that in the susceptible cultivar (63M80). The present findings suggest that Armarvirski3497 and Line-41 are candidate parental materials for breeding bird-resistant sunflower cultivars without losing seed oil productivity.

Key words: Bird Resistance, Breeding Materials, Globular seed, Seed Coat, Sunflower.

In Japan, sunflower is increasingly cultivated in rice-based rotational cropping systems for human consumption and for biodiesel fuel (Okada et al., 2008). Since the seeds are usually harvested by machine, the sunflower head must be sufficiently dry for harvesting. Thus, sunflower plants are left in the field for long periods, and are vulnerable to bird damage, which decreases the seed yield. Khaleghizadeh et al. (2009) identified the injurious bird species as European goldfinch, house sparrow, rook, hooded crow and so on. In Japan, the injurious birds are mainly oriental greenfinch, Carduelis sinica. The area of sunflower cultivation per farmer in Japan is not as large as in Europe, North America and so on. Therefore the total impact by birds is serious especially in such small fields. Thus, protection of the crops from bird damage is an important research subject in sunflower cultivation in Japan.

The characters of bird-resistant cultivars have been reported in sorghum. Perumal and Subramanian (1973) reported that a long-glumed cultivar was damaged less than other cultivars with shorter glumes. The awns and glumes influenced bird preference. Large glumes which envelop the grain apparently make feeding difficult for birds. Thus, awns and glumes were thought as the better morphological means for bird resistance (Bullard and York, 1996). Bullard et al. (1980) reported that tannins and phenolic compounds were the chemical means for bird resistance. Hoshino and Duncan (1981) reported that hybrids of sorghum which contained tannin had no bird damage, and that the tannin content varied with the environmental condition. Tipton et al. (1970) reported that the contents of tannic acid and total astringents in the grain were higher in the bird-resistant hybrids than in the susceptible hybrids. With the progress of grain development, the polyphenolic activity of these compounds increased until they dropped (Bullard et al., 1981). However, these compounds were less preferred humans as well as by birds. They may also lower the nutritional value. Then Ark-3048 was bred as a tannin-free bird-resistant sorghum (Tarimo, 2000), which had a significant level of dhurrin. The repellent was extractable with a polar solvent. So, the toxic substance can be removed by soaking or boiling in water. In sunflower, various factors contributing to bird damage have been reported. These factors can be categorized as bird-related or plant-related. Dedio (1995) reported that birds preferred sunflower cultivars with a higher oil and nutmeat content. Migrating birds, such as the common grackle, Quiscalus quiscula, preferred energy-rich foods such as sunflower (Homan et al., 1994). Seiler and Rogers (1987) reported that chaff length, head angle, plant height, stem angle, and the tight achene genotype contributed to bird resistance. Bullard (1988) reported that morphological characteristics of sunflower plants – concave heads and medium distance between head and stem – discouraged feeding by blackbirds. Rauf et al. (2008) studied the effects on bird resistance of a set of sunflower phenotypes: head shape, achene compactness,
stem orientation, and head orientation. They also reported that crop yield could be improved by selecting a highly concave head shape.

In Japan, a sunflower cultivar with bird-resistant characteristics has not been identified, and to our knowledge no papers have been reported on bird resistance. This paper evaluated sunflower genetic resource cultivars for bird-resistant traits and reported on the agronomic characteristics, yields, and quality of two candidates for breeding new sunflower cultivars with bird-resistant traits.

### Materials and Methods

1. **Preliminary field survey of genetic resources for bird-resistant traits.**

   The field survey was conducted in 2005 in the Kamondai Experimental Field (Tsukuba City, Ibaraki, Japan). Forty-six genetic resource cultivars (Table 1) and four F₁ hybrid cultivars, 63M80 (Pioneer Hi-Bred International, Inc., Johnston Iowa, USA), Hysun 450 (Pioneer Hi-Bred International, Inc., Johnston Iowa, USA), Hybridsunflower (Kaneko Seeds Co., LTD. Gunma, Japan) and North Queen (National Agricultural Research Center for Hokkaido Region, Hokkaido, Japan) were used. 63M80 was a popular cultivar especially in the Kanto district.

### Table 1. Bird-resistant variation in genetic resources and F1 cultivars.

| Resistance to bird feeding² | USA | Russia | Germany |
|-----------------------------|-----|--------|---------|
| Origin Cultivar Accession No. | RAA208 2200056  USA | RAA299 2200057  USA | J9 SF 1134/86/GG 2200060  Germany |
| Origin Cultivar Accession No. | RAA209 2200057  USA | HA302 209064  Russia | 63M80 224114  Germany |
| Origin Cultivar Accession No. | HA303 209065  HA290 209063  USA | RAA296 2200054  USA | North Queen 2200006  USA |
| Origin Cultivar Accession No. | HA300 209062  HA300 209063  USA | HA292 209059  HA294 209060  USA | 63M80 224114  Germany |
| Origin Cultivar Accession No. | HA301 209063  HA301 209063  USA | HYHYMK8931 33522  Russia | North Queen 2200006  USA |
| Origin Cultivar Accession No. | ARMARVIRSKIJ3497 33525  Germany | SMENA 33525  Russia | F1 63M80 224114  Germany |
| Origin Cultivar Accession No. | J9 SF 1134/86/GG 2200060  Germany | J7 SF 171/86/GG 224113  Germany | J12 SF 630/86/GG 2200059  Germany |
| Origin Cultivar Accession No. | SF 66/86/GG 2200058  Germany | VNIMK8883(VIR1961) 33529  Germany | SF 105/86/GG 2200061  Germany |
| Origin Cultivar Accession No. | J12 SF 630/86/GG 2200059  Germany | VNIMK8931(VIR1942) 33530  Germany | J8 SF 105/86/GG 2200061  Germany |
| Origin Cultivar Accession No. | CERNANKA66 33523  Germany | APSH 11 224115  India | CERNANKA66 33523  Germany |
| Origin Cultivar Accession No. | APSH 11 224115  India | EC 68415 224116  India | APSH 11 224115  India |
| Origin Cultivar Accession No. | MORDEN 296967  Russia | LINE-43 209130  Myanmar | MORDEN 296967  Russia |
| Origin Cultivar Accession No. | SERSIMK8931 33529  Germany | LINE-43 209130  Myanmar | SERSIMK8931 33529  Germany |
| Origin Cultivar Accession No. | MAJAK 33531  Germany | LINE-43 209130  Myanmar | MAJAK 33531  Germany |
| Origin Cultivar Accession No. | MAJAK 33531  Germany | LINE-43 209130  Myanmar | MAJAK 33531  Germany |
| Origin Cultivar Accession No. | LINE-43 209130  Myanmar | LINE-43 209130  Myanmar | LINE-43 209130  Myanmar |

1) At reproductive stage (R-9), with yellow and brown bracts, bird resistance was evaluated. Intermediate : more than 25% and less than 75% of a head is eaten, susceptible : more than 75% of a head is eaten, resistant : less than 25% of a head is eaten. Values represent numbers of genetic resources and F₁ cultivars.
Among the genetic resource cultivars used, 15 cultivars were from the USA, 10 cultivars were from Russia, 9 were from Myanmar, 7 were from Germany, 4 were from India and 1 was from Pakistan. They were sown on 30 May 2005 in two plots each. A plot consisted of 5 rows, each 2 m long and with plants spaced 0.3 m within rows and 0.75 m between rows. We broadcast uniformly a compound fertilizer prior to sowing to provide 8.4 g m\(^2\) each of N [as (NH\(_4\))\(_2\)P\(_2\)O\(_7\)], P (as P\(_2\)O\(_5\)), and K (as K\(_2\)O). The plots were located in an area that allowed unrestricted access of birds. Resistance to feeding by birds was estimated by evaluating achene damage in the 46 genetic resources and the four F\(_1\) hybrid cultivars at reproductive stage 9 (R9), when bracts became yellow to brown. This stage is generally regarded as physiological maturity. The stages were evaluated by the method of Schneiter and Miller (1981).

At physiological maturity, resistance to bird damage was categorized as resistant, intermediate, or susceptible. The sampled heads and seeds were dried in an oven at 60ºC for 18 hr (Izquierdo et al., 2002). The yield in each plot was determined from the harvest of 1.44 m\(^2\) measured in each of the two replicates for each cultivar. Thousand kernel weight was measured with two replicates for each sample.

### Table 2. Flowering and physiological maturity of the cultivars in 2005, 2007 and 2008.

| Cultivar | Sowing time (date) | Flowering\(^1\) (date) | Maturity\(^2\) (date) | Ripening period\(^3\) (days) |
|----------|--------------------|------------------------|------------------------|-----------------------------|
| 2005     |                    |                        |                        |                             |
| Arm.\(^4\) | 30 May             | 29 July                | 7 September            | 42                          |
| Line-41  | 30 May             | 24 July                | 5 September            | 36                          |
| 63M80    | 30 May             | 27 July                | 28 August              | 33                          |
| 2007     |                    |                        |                        |                             |
| Arm.     | 21 June            | 24 August              | 25 September           | 33                          |
| Line-41  | 21 June            | 22 August              | 21 September           | 31                          |
| 63M80    | 21 June            | 24 August              | 22 September           | 30                          |
| 2008     |                    |                        |                        |                             |
| Arm.     | 27 May             | 30 July                | 9 September            | 42                          |
| Line-41  | 27 May             | 29 July                | 8 September            | 42                          |
| 63M80    | 4 June             | 4 August               | 11 September           | 39                          |

1) Flowering date: 40–50% of tubulous flowers first bloomed.
2) Maturity date: the back side of 80–90% of heads turned yellow.
3) Ripening period: days from flowering to maturation.
4) Arm.: Armarvirskij3497.

3. Bird feeding experiment

Wild oriental greenfinches (Carduelis sinica) were housed in a room with controlled temperature (20ºC) and humidity (50%), under natural light, and fed on canary food and water. Eight birds were caged randomly, one bird per cage. Cage size was 36 cm wide, 29 cm long, and 40 cm in height. After 10 days of acclimatization to the housing conditions, the birds were fasted except for water from sunset of the day before the experiment to the start of the experiment. One experiment was performed with eight birds and the consumption of two sunflower cultivars was compared: Arm. vs. 63M80 or Line-41 vs. 63M80. Fifty seeds of each cultivar for each feeding experiment 100 seeds in total per experiment, which was enough food for a bird, were offered and the birds were allowed to feed freely on both types of seed in each experiment. Water was also freely available throughout the experiment. Seeds of one cultivar were marked and those of the other were not marked. The positions of trays and seed marking were varied; eight patterns of trays and seed markings were used for each feeding experiment. The experiments were started at 0830 with 3 hr allowed per experiment. Eight patterns of trays and seed markings were repeated three times, and each bird experienced a different pattern for each replicate. The birds were free to eat canary food and drink water after the end of each experiment until the start of the next replicate. After all replicates were finished, and the birds were confirmed to be healthy, they were released.

The number of seeds un eaten (whole seeds) in the cage, in the tray and in the bottom of the cage, were...
Fig. 1. Yield versus thousand kernel weight in the 2005 preliminary trial. ** Significant at the 0.01 level.

○ : Arm.; △ : Line-41; □ : 63M80;◆ : other cultivars.

Fig. 2. Photographs showing typical bird damage.
(a : Line-41, b : 63M80).

Fig. 3. Seeds dropped from sunflower plants.
(a : Line-41, b : 63M80).
was extracted with n-butyl alcohol. Oil content by weight and fatty acid composition of seeds relative to total fatty acids were determined by the method of Caviezel (Pendl et al., 1998) by using a gas chromatograph (B-820, Nihon Büch Co., Ltd., Tokyo). Individual fatty acid content was determined from the peak areas and calculated as the percentage of the total fatty acid content. Potassium, calcium and magnesium content were analyzed by atomic absorption spectrometry after wet digestion and calculated as the percentage to seed weight (David, 1959, 1960). Crushed seed samples were wet-digested by sequential treatment with nitric acid and perchloric acid by heating counted. The seed consumption was calculated by subtracting the number of whole seeds left at the end of the experiment from that of the total number of seeds offered initially (50 seeds per cultivar).

4. Seed analysis

The length, width, and thickness of whole seeds sampled were measured with vernier calipers. Seed coats were removed with tweezers, and their percentage to total seed weight was calculated. Oil content by weight and fatty acid composition were measured as follows: Two grams of whole seeds from each sample were crushed and the oil was extracted with n-butyl alcohol. Oil content by weight and fatty acid composition of seeds relative to total fatty acids were determined by the method of Caviezel (Pendl et al., 1998) by using a gas chromatograph (B-820, Nihon Büch Co., Ltd., Tokyo). Individual fatty acid content was determined from the peak areas and calculated as the percentage of the total fatty acid content. Potassium, calcium and magnesium content were analyzed by atomic absorption spectrometry after wet digestion and calculated as the percentage to seed weight (David, 1959, 1960). Crushed seed samples were wet-digested by sequential treatment with nitric acid and perchloric acid by heating counted. The seed consumption was calculated by subtracting the number of whole seeds left at the end of the experiment from that of the total number of seeds offered initially (50 seeds per cultivar).

### Table 3. Plant characteristics in 2007 and 2008 crops.

| Cultivar | Plant height (cm) | Stem length (cm) | Head size (cm) | Head thickness (cm) | Leaf number | Head to stem (cm) |
|----------|------------------|------------------|----------------|--------------------|-------------|-------------------|
| 2007     |                  |                  |                |                    |             |                   |
| Arm.     | 195.5 ± 4.1 a    | 185.0 ± 6.2 a    | 19.7 ± 0.4 a   | 2.9 ± 0.2 a        | 29.2 ± 0.7 a| 13.5 ± 1.1 a      |
| Line-41  | 176.3 ± 2.9 b    | 173.9 ± 1.7 b    | 18.7 ± 2.2 ab  | 2.7 ± 0.1 ab       | 28.7 ± 1.7 a| 13.0 ± 0.9 a      |
| 63M80    | 163.7 ± 3.6 c    | 151.7 ± 5.3 c    | 15.9 ± 1.3 b   | 2.5 ± 0.1 b        | 28.1 ± 1.7 a| 12.7 ± 0.4 a      |
| 2008     |                  |                  |                |                    |             |                   |
| Arm.     | 202.0 ± 10.4 a   | 195.0 ± 8.7 a    | 21.3 ± 1.6 a   | 2.9 ± 0.4 a        | 31.1 ± 0.9 a|                   |
| Line-41  | 184.5 ± 6.4 b    | 176.8 ± 5.4 b    | 21.7 ± 0.4 a   | 2.7 ± 0.3 a        | 29.4 ± 1.9 a|                   |
| 63M80    | 172.7 ± 3.1 b    | 166.5 ± 3.2 b    | 17.9 ± 0.9 b   | 2.5 ± 0.4 a        | 31.5 ± 0.9 a|                   |

1) Arm.: Armarvinskij3497.
Values represent means ± standard deviation of four blocks in 2007, and that of three blocks in 2008. Values with the same letters in each column are not significantly different at P=0.05 by Tukey’s test.

### Table 4. The plant and ecological characters in 2007 and 2008 crops.

| Cultivar | Head shape\(^1\) | Head angle\(^2\) | Lodging tolerance\(^3\) | Resistance to bird feeding\(^4\) |
|----------|------------------|------------------|--------------------------|-------------------------------|
| 2007     |                  |                  |                          |                               |
| Arm.     | slightly convex  | horizontal~     | slightly susceptible     | resistant                      |
| Line-41  | slightly convex  | horizontal~     | intermediate             | resistant                      |
| 63M80    | flat             | horizontal~     | intermediate             | susceptible                    |
| 2008     |                  |                  |                          |                               |
| Arm.     | slightly convex  | horizontal~     | slightly susceptible     | resistant                      |
| Line-41  | slightly convex  | horizontal~     | intermediate             | resistant                      |
| 63M80    | flat             | horizontal~     | intermediate             | susceptible                    |

1) Shape of transverse section of tubulous flowers.
2) Angle of a head when 1/3 of tubulous flowers in a head bloomed.
3) Observed when the differences between cultivars are clear: Intermediate: about 50% of the plants lodged; slightly susceptible: about 50–75% of the plants have lodged.
4) At the appropriate time for observation when the differences between cultivars are clear. Resistant: less than 25% per a head are eaten by birds. Susceptible: more than 75% per a head are eaten by birds.
5) Arm. is Armarvinskij3497.
Statistical analysis

Results are presented as mean ± standard deviation. Analysis of variance was performed with the statistics program SPSS 11.0J (SPSS, Inc., Chicago, USA). Data were subjected to Tukey’s multiple-range tests to compare mean values at the 5% and 1% levels of significance.

Results

1. Field survey of genetic resources and field trial of bird-resistant traits

Of the 46 genetic resource cultivars and four F1 hybrid cultivars tested in the 2005 preliminary trial, 22 were bird resistant, 23 were intermediate, and five were susceptible (Table 1). From the cultivars resistant to birds in this survey, we chose two cultivars (Arm. and Line-41) for further study, because their thousand kernel weights and yields were comparatively high (Fig. 1). Yield was significantly correlated with one thousand kernel weight.

Flowering and physiological maturity characteristics of Arm., Line-41, and 63M80 in the preliminary survey in 2005 and in the field trials in 2007 and 2008 are shown in Table 2. The earliest-maturing cultivar was 63M80, and Arm. was the latest. In 2007, all three cultivars were sown later than in 2005 or 2008. The later sowing date shortened the ripening period since sunflower is a short-day plant.

Plant characteristics in 2007 and 2008 are shown in Table 3 and Table 4. The plant height, stem length, and the diameter and thickness of the head tended to be larger in Arm. and Line-41 than in 63M80; especially in Arm.; most of these differences were statistically significant in both years (Table 3). The head-to-stem distance did not vary significantly with the cultivar in 2007 (Table 3). The head shapes of Arm. and Line-41 were slightly convex while that of 63M80 was flat (Table 4). Head angle was similar in the three cultivars (Table 4). The lodging tolerance of Arm. was slightly lower than that of the other two cultivars (Table 4).

Bird resistance clearly differed among the three cultivars. In the field, the seeds of 63M80 experienced serious bird damage by oriental greenfinch, *Carduelis sinica* in maturing time (Fig. 2). Thus, though the hybrid plants

Table 3. Changes in thousand kernel weight and yield over time in 2007 and 2008 crops.

| Year | Harvest Date | Cultivar | Thousand kernel weight (g) | Yield (g plant⁻¹) |
|------|--------------|----------|---------------------------|------------------|
| 2007 | 3 October    | Arm. ¹   | 79.1 ± 3.9 a              | 56.3 ± 8.2 a     |
|      |              | Line-41  | 65.6 ± 9.5 ab             | 46.4 ± 7.4 ab    |
|      |              | 63M80    | 60.2 ± 7.5 b              | 42.4 ± 5.6 b     |
| 19 October | Arm.        | 85.2 ± 5.0 a              | 43.0 ± 6.5 a     |
|        | Line-41     | 71.8 ± 1.6 b              | 35.4 ± 2.8 a     |
|        | 63M80       | 64.8 ± 1.7 c              | 27.6 ± 5.3 a     |
| 24 October | Arm.        | 88.2 ± 5.2 a              | 44.4 ± 4.5 a     |
|         | Line-41     | 81.1 ± 3.0 a              | 36.4 ± 9.8 a     |
|         | 63M80       | 61.0 ± 8.7 b              | 18.8 ± 5.3 b     |
| Harvest Date (H) * |          |          |                          |                  |
| Cultivar (C) **     |          |          |                          |                  |
| H × C n.s. n.s.     |          |          |                          |                  |
| 2008 | 8 September  | Arm. ¹   | 69.7 ± 6.4 a              | 63.8 ± 5.6 a     |
|       |              | Line-41  | 73.2 ± 4.6 a              | 69.1 ± 8.2 a     |
|       |              | 63M80    | 53.3 ± 10.6 b             | 54.5 ± 11.4 a    |
| 17 September | Arm.        | 70.9 ± 7.3 a              | 57.2 ± 6.1 ab     |
|           | Line-41     | 71.3 ± 5.3 a              | 67.4 ± 7.8 a     |
|           | 63M80       | 54.6 ± 5.9 b              | 45.5 ± 1.4 b     |
| 24 September | Arm.        | 85.9 ± 7.0 a              | 46.1 ± 7.8 a     |
|           | Line-41     | 76.4 ± 8.4 a              | 53.1 ± 7.5 a     |
|           | 63M80       | 61.2 ± 3.5 b              | 39.7 ± 8.1 a     |
| 30 September | Arm.        | 89.1 ± 1.4 a              | 57.3 ± 3.7 a     |
|             | Line-41     | 86.3 ± 6.7 a              | 60.3 ± 8.5 a     |
|             | 63M80       | 64.3 ± 3.3 b              | 43.7 ± 14.0 a    |
| 7 October | Arm.        | 80.5 ± 13.4 a             | 59.5 ± 2.5 a     |
|           | Line-41     | 78.5 ± 15.7 a             | 47.9 ± 3.7 ab    |
|           | 63M80       | 64.7 ± 5.2 a              | 35.3 ± 8.8 b     |
| Harvest Date (H) * |          |          |                          |                  |
| Cultivar (C) **     |          |          |                          |                  |
| H × C n.s. n.s.     |          |          |                          |                  |

1) Arm.: Armarvinskij3497

Values for eight birds with standard deviation of three replicates. Values with the same letters do not significantly differ at P = 0.05 by Tukey's test.

Table 6. Bird feeding test.

| Cultivar | Food intake (seeds days⁻¹) | Dropped food (seeds days⁻¹) |
|----------|---------------------------|-----------------------------|
| Arm. ¹   | 13.9 ± 2.0 b              | 6.0 ± 0.7 b                 |
| Line-41  | 15.6 ± 1.2 b              | 6.2 ± 0.6 b                 |
| 63M80    | 19.2 ± 1.6 a              | 3.5 ± 0.6 a                 |

1) Arm.: Armarvinskij3497.

Values represent mean ± standard deviation of four blocks in 2007, and three blocks in 2008. Values with the same letters do not significantly differ at P = 0.05 by Tukey's test.

on a hot-plate. The samples were filtered and the residues were heated at 500°C for two hours. The weight of residual ash after heating was recorded as the silica content. All measurements were repeated two or three times depending on the cultivar.
of 63M80 were mature, their thousand kernel weights actually decreased in later harvesting times as the birds continued to feed (Table 5). There was no serious seed loss to birds in Arm. and Line-41 in the field. They had a higher thousand kernel weight with maturation except for that at 7 October 2008. Because of greater standard deviation within each cultivar, thousand kernel weights were not statistically significantly different. The difference between Arm. or Line-41 and 63M80 in thousand kernel weight and yield tended to increase as the harvest progressed. In the field, some whole (uneaten) seeds were found beneath the Arm. and Line-41 plants (Fig. 3a). In contrast, many discarded seed coats were found near the base of 63M80 plants at maturity (Fig. 3b).

2. Bird feeding experiment

Oriental greenfinch Carduelis sinica ate the seeds of all cultivars. The numbers of Arm. and Line-41 seeds eaten by them were significantly smaller than that of 63M80 seeds (Table 6). Moreover, the numbers of seeds which were not eaten by birds were significantly larger in Arm. and Line-41 than in 63M80 (Table 6).

3. Analysis of seeds

Seed quality characteristics at harvest in 2007 are shown in Table 7. Seeds of Arm. and Line-41 were significantly wider and thicker than those of 63M80 (Table 7). The seed-shape of these two lines was globular, while that of 63M80 was thin (Fig. 3). Though there was no significant difference in total oil content among the three lines, the oleic acid contents of Arm. and Line-41 were significantly lower and their linoleic acid contents were significantly higher than those of 63M80. The percentage of seed coat weight to total seed weight was higher in Arm. and Line-41 than in 63M80. Especially the percentage was significantly higher in Line-41 than in 63M80 (Table 7).

The potassium contents of the seed kernels of Arm. and Line-41 tended to be higher than that of 63M80, although the differences were not statistically significant. The contents of magnesium in the seed kernels of Arm., Line-41 and 63M80 were not significantly different (Table 8). In the seed coat, the contents of potassium in that of Arm. and 63M80 were significantly lower than that of Line-41 (Table 9). The calcium and magnesium contents of the seed coat were lower than that of 63M80 also, though there was not statistically difference between Arm. and 63M80. The silica contents in the seed coats of Arm. and Line-41 tended to be lower than that of 63M80, the content in Arm. was lower than that of 63M80 significantly (Table 9).

Discussion

In this study, we identified two highyield, bird-resistant sunflower cultivars, Arm. and Line-41, from an initial screen of 46 genetic resources. We assessed their resistance to feeding by birds in the field and in the laboratory, and compared various seed, plant, and agricultural characteristics to those of a bird-susceptible control F1 hybrid cultivar, 63M80.

1. Plant characteristics

Gross and Hanzel (1991) identified long involucral bracts, horizontally oriented heads, concave heads, and long head-to-stem distances as features that confer resistance to feeding by birds. In our study, head-to-stem
distance was similar among the three cultivars so we could not assess this feature. Mah (1988) also reported that concave heads reduced bird-feeding efficiency. The resistant cultivars Arm. and Line-41 had slightly convex heads (and that of the susceptible control, 63M80, was flat), so we could not assess whether concave heads affected bird feeding efficacy.

2. Agricultural characteristics

Factors related to the timing of crop planting, maturation, and harvest may also affect bird resistance, as well as yield. Killi et al. (2004) reported that though the average protected seed yield did not vary with the cultivar, the planting date affected the extent of bird damage. The resistant cultivars identified in our study, however, showed bird resistance irrespective of sowing date.

Our field experiments showed that Arm. and Line-41 had a somewhat longer ripening period than 63M80, and they also matured somewhat later. Because sunflower is a short-day plant, however, the later the sowing date of the two bird-resistant cultivars, the shorter the day length, resulting in a shorter ripening period and earlier maturation; in addition, the difference in ripening period between the cultivars decreased.

Arm. was slightly more prone to lodging than the other two cultivars. This is probably because it is taller and has a larger head size than the other cultivars.

3. Seed shape, and oil and chemical content

In our study, the bird-resistant cultivars had globular seeds with a heavy seed coat while the susceptible F1 hybrid cultivar had thin seeds and with somewhat lighter seed coats. Therefore it appeared to be difficult for the small greenfinch Carduelis sinica to eat these bird-resistant cultivars.

Chemical and oil contents of seeds and seed coats were other possible factors of bird resistance. In grain sorghum, Bullard and York (1996) reported that tannin contents in grains were related to bird resistance. Bullard (1988) and Mason et al. (1989) reported that blackbirds preferred sunflower cultivars with a high oil content in their seeds. However, since the three cultivars we studied had a similar oil content, we were unable to assess how this factor affected bird resistance. We hypothesized that the inorganic component content of seed kernels and seed coats could influence bird preference as a substitute for hardness of seed coat and kernel. Mah (1988) reported that tough fibrous hulls reduce bird-feeding efficiency. In our study, seed coats of both Arm. and Line-41 contained less potassium than 63M80, and Line-41 contained less calcium and magnesium than 63M80. Thus, the measured mineral contents were not lower in 63M80 than Arm. and Line-41. Thus these components may not be related to bird-resistance, but we did not measure seed coat hardness and toughness directly.

In conclusion, this study identified two sunflower cultivars with bird-resistant traits. Mah et al. (1990) reported that the development of bird-resistant sunflowers may represent a cost-effective strategy for reducing blackbird depredation. We propose that, in Japan, reducing bird damage by greenfinches might also be cost-effective for sunflower production. The factors most likely to explain bird-resistance of the cultivars we studied were the globular shape of the seeds and the heavy seed coat. In addition to bird resistance, Arm. and Line-41 had a high yield, and were fixed cultivars, not F1 hybrid cultivars. However, there are some unfavorable characters such as higher plant height and lower lodging tolerance than the susceptible F1 hybrid cultivar 63M80. As the next step, we will use Arm. and Line-41 as starting materials for breeding a new sunflower variety with bird-resistant traits.

References

Bullard, R.W., Garrison, M.V., Kilburn, S.R. and York, J.O. 1980. Laboratory comparisons of polyphenols and their repellent characteristics in bird-resistant sorghum grains. J. Agric. Food Chem. 28: 1006-1011.

Bullard, R.W., York, J.O. and Kilburn, S.R. 1981. Polyphenolic changes in ripening bird-resistant sorghums. J. Agric. Food Chem. 29: 973-981.

Bullard, R.W. 1988. Characteristics of bird-resistance in agricultural crops. Proc. Vertebr. Pest Conf. 13: 305-309.

Bullard, R.W. and York, J.O. 1996. Screening grain sorghums for bird tolerance and nutritional quality. Crop Protection 15: 159-165.

Table 9. Content of K, Ca, Mg, and SiO in seed coat.

| Cultivar | Seed coat |
|----------|-----------|
|          | K (%)     | Ca (%) | Mg (%) | SiO (%) |
| Arm.     | 0.911 ± 0.048 b | 0.349 ± 0.004 ab | 0.248 ± 0.006 a | 0.035 ± 0.013 b |
| Line-41  | 0.893 ± 0.101 b | 0.301 ± 0.022 b | 0.195 ± 0.020 b | 0.068 ± 0.006 ab |
| 63M80    | 1.280 ± 0.033 a | 0.441 ± 0.036 a | 0.257 ± 0.014 a | 0.076 ± 0.027 a |

1) Arm.: Armavirskij 3497. Values represent means ± standard deviation of four blocks. Values with the same letters are not significantly different at P = 0.05 by Tukey’s test.
David, D.J. 1959. Determination of Calcium in plant material by atomic-absorption spectrophotometry. Analyst 84: 536-545.

David, D.J. 1960. The determination of exchangeable Sodium, Potassium, Calcium and Magnesium in soils by atomic-absorption spectrophotometry. Analyst 85: 495-503.

Delio, W. 1995. Association of sunflower achene color with other achene characters and bird preference. Canadian J. of Plant Science 75: 377-380.

Gross, P.L. and Hanelt, J.J. 1991. Stability of morphological traits conferring bird resistance to sunflower across different environments. Crop Sci. 31: 997-1000.

Homan, H.J., Linz, G.M. and Bleier, W.J. 1994. Effects of crop phenology and habitat on the diet of common grackles (Quiscalus quiscula). Am. Midl. Nat. 131: 383-385.

Hoshino, T. and Duncan, R.R. 1981. Bird damage and tannin content in grain sorghum hybrids under different environments. Jpn. J. Crop Sci. 50: 332-337.

Izquierdo, N., Aguirrezabal, L., Andrade, F. and Pereyra, V. 2002. Night temperature affects fatty acid composition in sunflower oil depending on the hybrid and the phenological stage. Field Crop Research 77: 115-126.

Khaleghizadeh, A., Khormali, S., Espahbodi, A., Alizadeh, E. and Khchebaghi, A.H. 2009. Identification of injurious birds on sunflower and their damage rate effects of some morphological factors of sunflower on bird damage. In Agronomy and Horticulture 21: 86-97.

Kilf, F., Kilic, B. and Goree, K. 2004. The effect of different planting dates on the extent of bird damage in confection and oilseed sunflowers. J. of Agronomy 3: 36-39.

Mah, J. 1988. Feeding behavior of red-winged blackbirds on sunflowers with different bird-resistant features. PhD dissertation, North Dakota State University, Fargo, North Dakota, 107pp.

Mah, J., Linz, G. M. and Hanelt, J.J. 1990. Relative effectiveness of individual sunflower traits for reducing red-winged blackbird depredation. Crop Protection 9: 359-362.

Mason, J.R., Dolbeare, R.A., Woronecki, P.P. and Bullard, R.W. 1989. Maternal and varietal influences on sunflower consumption by red-winged blackbirds. J. of Wildlife Management 53: 841-846.

Okada, K., Matsuoka, M., Yasumoto, S., Iijima, W., Tagohi, T. and Tanisawa, K. 2008. Production and utilization of rapeseed and sunflower for the purposes of bioenergy and revitalization of rural communities. J. of Crop Research 53: 85-90.

Pendl, R., Bauer, M., Caviezel, R. and Schulthess, P. 1998. Determination of total fat in feeds and foods by the Caviezel method, based on a gas chromatographic technique. J. of AOAC International 81: 907-917.

Perumal, R.S. and Subramanian, T.R. 1973. Studies on panicle characters associated with bird resistance in sorghum. Madras Agrie. J. 60: 256-258.

Rauf, S., Sadaqat H.A. and Naveed, A. 2008. Effect of moisture stress on combining ability variation for bird resistance traits in sunflower (Helianthus annuus L.). Pakistan J. of Botany 40: 1319-1328.

Scheure, A.A. and Miller, J.F. 1981. Description of sunflower growth stages. Crop Sci. 21: 901-903.

Seiler, G.J. and Rogers, C. 1987. Influence of sunflower morphological characteristics on achene predation by birds. Agriculture, ecosystems and environment 20: 59-70.

Tarimo, T.M.C. 2000. The cyanogenic glycoside dhurrin as a possible cause of bird-resistance in Ark-3048 sorghum. In R.A. Cheke et al., eds., Proceedings of a Workshop on “Research Priorities for Migrant Pests of Agriculture in Southern Africa”. Pretoria. 103-111.

Tipton, K.W., Floyd, E.H., Marshall, J.G. and McDevitt, J.B. 1970. Resistance of certain grain sorghum hybrids to bird damage in Louisiana. Agronomy J. 62: 211-213.