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Resistance to Cotton Aphid (*Aphis gossypii* G.) in Melon: Its Mechanism and Selection Methods

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Abstract
Population of aphids on a melon cultivar, PMAR No. 5, was much smaller as compared with that on other cultivars. Incidences of leaf curling and stunting caused by aphids were not prevalent in PMAR No. 5 in both mass and isolated infestations. These results indicate that PMAR No. 5 is resistant to aphid. On resistant plants, aphids could proliferate slowly, and migrate rarely from others. It is very likely that antibiosis and nonpreference in melon plants operate as resistance. The resistance is genetically a dominant trait governed possibly by a single major gene. Aphid resistant plants could be selected on the basis of a leaf curling index with a supplementary information on aphid population size resulting in ten days after aphid placement in a mass infestation test. Aphid resistance manifests itself on the above-the-ground part of the plants, having no connection with root-related substance. No relationship was seen between the trichomes or substances on leaves and the aphid resistance. In the field tests, plants possessing aphid resistance were almost free from infection of virus mediated by aphids, and use of insecticides for aphids was generally not required. Several inbred lines were derived from the hybrids between PMAR No. 5 and Japanese cultivars of an EARL'S FAVORITE type. Some of the F1 hybrids, using those inbred lines as parents art expected to be released as commercial varieties in Japan.

Discipline: Horticulture
Additional key words: breeding, Cucumis melo L., inheritance, insect resistance

Introduction

Aphid is one of the most noxious insects in farm products. In melon plants, predominant is, among others, cotton aphid (*Aphis gossypii* G.). It causes leaf curling and stunting in plants and carries viral diseases. In growing melon, therefore, it is vital to protect the plants from aphids in appropriate ways such as a spray of insecticides and/or a protective covering for the plants. In practice, however, it is very difficult to completely protect melon plants against cotton aphids, since they reproduce in a short period and infest multifarious species of plants. It is strongly required to establish a systematic method for protection, including use of resistant melon cultivars. Toward this end, Kishaba et al. (1971) found a breeding material having aphid resistance in melon, whereby an inbred line of muskmelon (LJ90234) was derived[1,5]. Up to date, however, very few cultivars have been added for commercial use[3,8].

The present paper attempts to review results of the study on mechanism of aphid resistance of a melon cultivar, PMAR No. 5, which possesses the same resistance gene with LJ90234. It also discusses some genetic issues in relation to a breeding method to develop a new variety with aphid resistance.

Biotic responses of aphids to melon cultivars

Two cultivars of melon, i.e. PMAR No. 5 and EARL'S–K, were subjected to comparative analyses regarding their aphid resistance. In the early growing stage of the plants just after foliation of the first true leaf, five aphids were placed on each plant for a mass infestation test. During the first 6 days after placement, aphids did not increase (Fig. 1). On the 7th day after placement, aphids (apterous adults

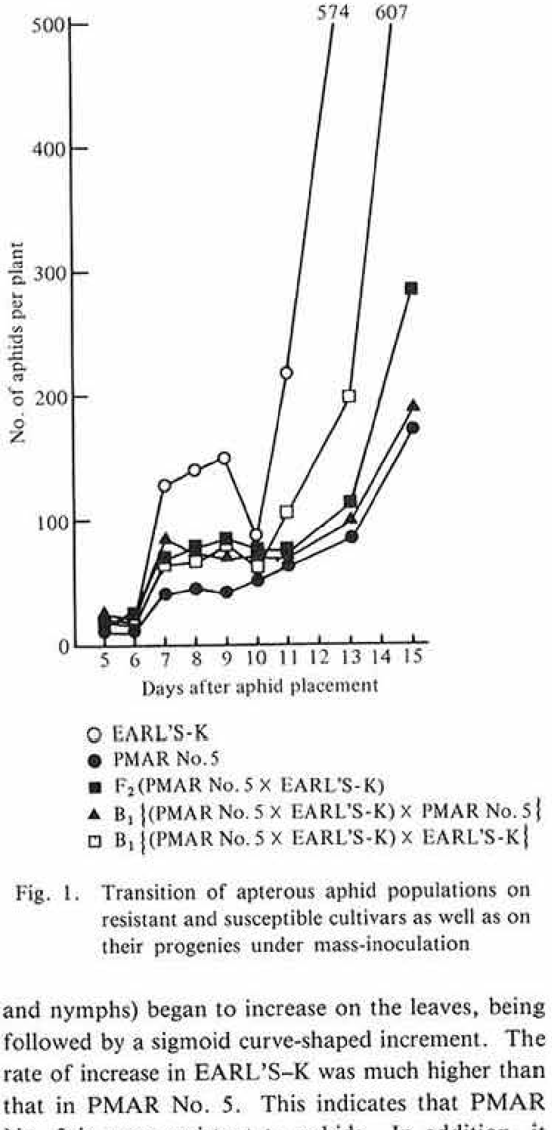

Fig. 1. Transition of apterous aphid populations on resistant and susceptible cultivars as well as on their progenies under mass-inoculation

and nymphs) began to increase on the leaves, being followed by a sigmoid curve-shaped increment. The rate of increase in EARL'S-K was much higher than that in PMAR No. 5. This indicates that PMAR No. 5 is more resistant to aphids. In addition, it suggests that the aphids on the resistant cultivar take more time in growing up to be adults than those on the susceptible ones. PMAR No. 5 showed very little leaf-curling and stunting caused by the aphids, while the leaves in EARL'S-K, the susceptible cultivar, were seriously curled, stunted, and some plants were dead in later stage.

With the purpose of identifying (1) biotic potential of aphids on individual resistant plants and (2) acceptance of aphid migrants by the host plants, aphids were placed on each of the resistant and susceptible cultivars. These two types of plants were grown in isolation cages in two manners: i.e. alternately and unitarily (Fig. 2). Population of nymphs on EARL'S-K continued to increase in size until 8 days after placement in each cage. Thereafter, it declined as a most-likely result of serious leaf curling and stunting caused by the infestation on juvenile plants taking place just before foliation of the first true leaf. On the other hand, aphid population on the PMAR No. 5 plants mix-located with a susceptible cultivar augmented faster than that on its unitary isolated plants at first. Later on, however, the number of aphids decreased in proportion to the reduction of aphid population on the susceptible cultivar in the same cages. This result indicates that only a small number of aphids per unit leaf area could be fed on a resistant cultivar.

A great number of alate aphids were produced on the EARL'S-K plants in accordance with the decrease in apterous adults and nymphs. On the other hand, a few winged aphids could be reared on the PMAR No. 5 plants both in the unitarily as well as in the alternately planted cages. This result demonstrates that alate aphids on the susceptible plants hardly move onto the resistant plants.

Apart from the above-mentioned arrangement of isolation cages with aphid-placed plants, sets of aphid-free melon plants, each including both of the susceptible and resistant cultivars, were placed at a distance of 2 m from an aphid source (Fig. 3). It was found that a sizable population came out on the plants of EARL'S-K due to aphid migration from the infested source-plants, while very few aphids were observed on the PMAR No. 5 plants throughout the period of the experiment.

It is concluded therefore that on resistant cultivars, aphids can only proliferate slowly, and rarely migrate onto them. It seems that antibiosis and nonpreference of melon plants operate as resistance[9], as suggested by Bohn (1972)[1,2].

Genetic basis of aphid resistance

PMAR No. 5, EARL'S-K and the progenies of their hybrids were subjected to a mass-infestation test on aphid resistance (Table 1). The F_1 between these two cultivars, and its backcrossed line to PMAR No. 5 were both resistant to aphids with the same level as PMAR No. 5. However, the F_2 and B_1 plants derived from backcrossing to EARL'S-K were segregated into resistant and susceptible plants. A

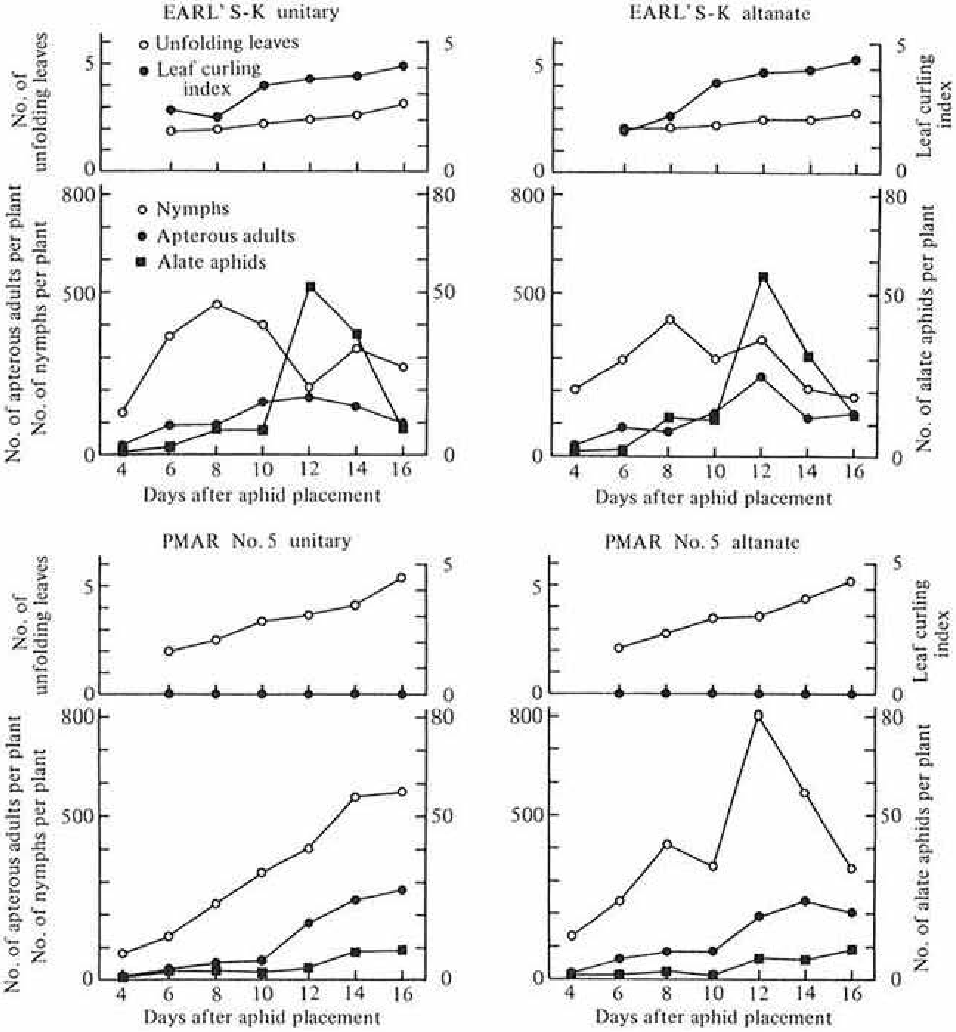

Fig. 2. Transition of aphid populations and plant damages on resistant and susceptible cultivars under isolated-inoculation
Leaf curling indices refer to as 0: completely flat leaves, 1: slight curling, 2: distinct, 3: moderate damage, 4: severe curling damage in every leaf, and 5: leaves or plants dead.

greater rate of resistant plants were seen in F_2 than in B_1. This result suggests that the aphid resistance in melon be genetically a dominant trait, and that it be governed by a single major gene, since the progenies showed a rather simple segregation in both leaf curling and aphid population pattern on the plants[6,10]. Therefore, the F_1 hybrids could easily make use of this aphid resistance. Some susceptible progenies were also derived, though rarely, from a resistant plant that was regarded as a dominant homozygote. This implies that there is a possibility that minor genes are also associated with aphid resistance.

Selection methods of aphid resistance

Since the size of aphid population on melon leaves is greatly affected by environmental and material conditions, it is necessary to be supplemented by other measures in evaluating aphid resistance of melon

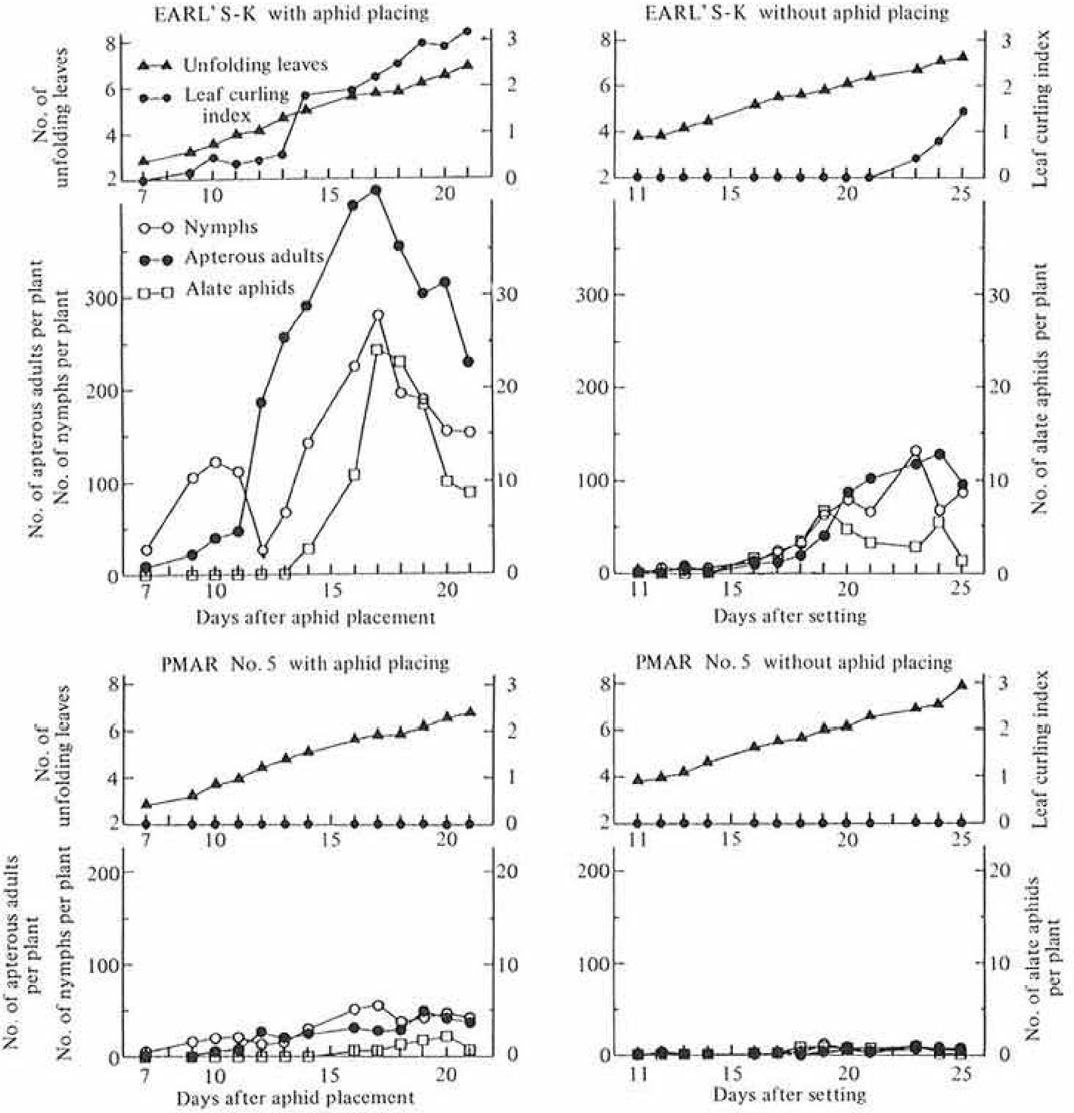

Fig. 3. Migration of aphid on resistant and susceptible cultivars from an aphid source
Plants were set at distance of 2 m from an aphid source.
The plants which aphids placed on were covered with isolation cages. Leaf curling indices refer to the note in Fig. 2.

plants. Toward this end, it was found that degree of leaf curling caused by aphids hereinafter referred to as "a leaf curling index", was a suitable indicator of resistance of the plants. Resistant plants were obtained among the progenies from those plants which had been ranked as resistant on the basis of combined measures of aphid population size and leaf curling index. On the other hand, there existed susceptible materials only among the progenies originating from the plants ranked as susceptible with the same measures (Table 2). The leaf curling index would provide easier and more effective measurements in determining characteristics of aphid resistance than the size of aphid population does. However, since plant tolerance against aphids might operate without antibiosis in the resistance system,

Table 1. Variation of aphid populations and leaf curling indices on PMAR No. 5 and its progenies

Cultivar and progeny[a)]	No. of plants tested	Frequencies (%) Range of aphid populations/plant[b)]						Leaf curling indices[c)]			
		-50	-100	-150	-200	-250	251-	0	1	2	3
SHINJU-100	24	8	25	25	4	13	25	0	38	38	25
EARL'S-K	48	8	6	8	15	25	38	0	46	46	8
PMAR No. 5	60	58	37	5	0	0	0	78	20	0	2
$F_1(P \times K)$	40	23	38	28	8	5	0	70	23	3	5
$F_2(P \times K)$	63	29	32	16	16	3	5	33	46	16	5
$B_1\{(P \times K) \times K\}$	47	21	17	19	19	9	15	21	34	23	21
$B_1\{(P \times K) \times P\}$	52	54	33	12	2	0	0	56	33	10	2
$B_1\{K \times (P \times K)\}$	55	31	33	9	9	0	18	20	42	24	15
$B_1\{P \times (P \times K)\}$	47	28	32	21	11	4	4	47	47	4	2

a): P and K show cultivars PMAR No. 5 and EARL'S-K, respectively.
b): Nine days after 5 aphids placement.
c): Twelve days after aphids placement. 0; Flat leaf, 1; Slight curling, 2; Distinct curling, 3; Moderate leaf damage.

Table 2. Aphid populations and leaf curling on progenies from selected plants

Cultivar and progeny[a)]	Combination[a)]	No. of plants tested	Frequencies (%) Leaf curling indices[b)]						Aphid population indices[c)]					
			0	1	2	3	4	5	0	1	2	3	4	5
$PK\text{-}S\text{-}S_{(s)}$[d)]	$F_3(P \times K)$	75	1	19	31	40	9	0	0	35	21	41	3	0
PK-S-S	"	80	83	14	3	0	1	0	45	51	3	1	0	0
$PK\text{-}K_1\text{-}S$	$S_1[B_1\{(P \times K) \times K\}]$	64	38	41	16	5	2	0	31	55	9	5	0	0
$PK\text{-}K_2\text{-}S$	"	76	62	17	15	4	3	0	46	38	8	7	1	0
PK-P-S	$S_1[B_1\{(P \times K) \times P\}]$	80	93	6	1	0	0	0	48	46	6	0	0	0
K-PK-S	$S_1[B_1\{K \times (P \times K)\}]$	76	67	9	20	3	1	0	26	45	25	3	1	0
$P\text{-}PK_1\text{-}S$	$S_1[B_1\{P \times (P \times K)\}]$	66	58	12	17	11	2	2	32	32	29	6	2	0
$P\text{-}PK_2\text{-}S$	"	74	91	7	3	0	0	0	57	43	0	0	0	0
SHINJU-100		24	4	25	25	33	13	0	0	33	58	8	0	0
HARUKEI No. 3		47	0	4	26	40	28	2	9	26	30	36	0	0
EARL'S-K		44	0	7	21	50	23	0	5	21	36	32	7	0
PMAR No. 5		57	67	19	4	7	4	0	39	51	11	0	0	0
$F_1(P \times K)$		48	98	0	2	0	0	0	8	63	29	0	0	0

a): See Table 1.
b): See the note in Fig. 2.
c): Aphid population on individual plant refers to as 0 (no or rare aphids) to 5 (so many aphids).
d): $PK\text{-}S\text{-}S_{(s)}$ is the progeny of the parent which was selected as a susceptible individual, and others are the progenies of resistant parents.

it would be required to take into account the aphid population as well for selecting resistant plants. In case where aphids are placed on juvenile plants just before the foliation of the first true leaf, it is very likely that the difference in aphid population between the resistant and susceptible plants is rather small due to severe damages in the susceptible materials.

It is therefore concluded that aphid resistant plants could be selected on the basis of a leaf curling index with a supplementary information on aphid population size in ten days after aphid placement. In addition, it would not be necessary to analyze aphid resistance in details for every generation in establishing inbred lines, because the relevant genetics are rather simple.

Mechanisms of aphid resistance

An experiment on reciprocal grafting between resistant and susceptible cultivars was undertaken. The

Table 3. Manifestation of aphid resistance on grafted plants

Scion/stock[a)]	No. of unfolding leaves	No. of aphids per plant			Leaf curling indices[b)]
		Alate aphids	Apterous adults	Nymphs	
K/K	5.0	5.8	226.8	234.4	1.6
P/P	5.0	0.0	9.0	77.5	0.0
P/P	3.6	0.3	2.9	20.0	0.0
K/P	5.0	7.0	214.3	313.0	1.7

a): See Table 1.
b): See the footnote in Fig. 2.
Investigations were carried out in 24 days after aphid placement.

Table 4. Length and density of trichomes at lower surface of leaves

Cultivar and progeny	No. of plants tested	Length of trichomes[a)] (μm)	No. of trichomes per mm^2
PMAR No. 5	20	222 ± 24.8[b)]	43.2
SHINJU-100	20	169 ± 15.7	49.0
SUNDAY	20	157 ± 13.9	-
NICE	20	164 ± 16.1	-
EARL'S-K	20	166 ± 15.4	-
NATSUKEI No. 6	20	147 ± 10.9	-
AKIKEI No. 2	20	150 ± 9.3	-
F_1(EARL'S-K × PMAR No. 5)	20	168 ± 16.4	-
F_1(NATSUKEI No. 6 × PMAR No. 5)	20	169 ± 17.7	-
F_1(AKIKEI No. 2 × PMAR No. 5)	20	185 ± 15.4	-

a): Fifty trichomes per plant were measured.
b): Mean ± standard deviation.

result of this experiment showed that the phenotype of a grafted plant in aphid resistance depended primarily upon traits of the scion (Table 3). Therefore, aphid resistance relates to the aerial part of the plant, having no relation to root substance.

In soybean plants, trichomes on leaves and pods participate in tolerance against the soybean beetle, soybean pod gall midge and soybean pod borer. PMAR No. 5 has longer trichomes at the lower surface of its leaves and various organs, compared with other cultivars. Short trichome is genetically a dominant character (Table 4). Densities of trichomes on the young leaves are not significantly different between the resistant and susceptible cultivars. Therefore, the trichomes on the leaves have no relation to aphid resistance in melon.

In cucumber, it is reported that bitter phenotypes are less favorable for aphids[4)]. But in melon, it could not be identified that extracts, either crude or fractional, from leaves of the resistant cultivar controlled the aphid population on leaves and artificial diets as well. Steam distillations from leaves were also analyzed on a gas-chromatography, but no specific substance has been detected in aphid resistant plants so far.

As mentioned above, the mechanism of aphid resistance and the relevant component factors have not been identified yet. Further studies are required to establish an improved breeding method for aphid resistance in melon.

Implications of aphid resistance for melon production

In the field tests, very few plants selected for aphid resistance showed symptoms of viral diseases after planting, whereas susceptible plants showed heavy incidences of mosaic and stunting, even under a slight aphid infestation.

In a plastic greenhouse, where applications of

Table 5. Resistance to aphids in field tests

Cultivar	Aphid population indices[a]
Breeding lines[b]	0.7
PMAR No. 5	0.8
EARL'S-K	5.0
H84S-10	4.4
H84S-4	4.0
SHINJU-100	2.0
HARUKEI No. 3	3.8
NATSUKEI No. 6	3.8
Honey-dew	5.0

a): Aphid population on individual plants refers to as 0 (no or rare aphids and plants are not damaged) to 5 (many aphids and plants are almost dead).
b): Average of 23 breeding lines which were selected as aphid resistant lines.

insecticides were discontinued after fruit-setting, there were serious attacks of aphids on commercial varieties; some plants were dead before harvesting. However, PMAR No. 5 and other resistant inbred lines under test were almost free from aphids and no plant damages resulted (Table 5).

In summary, melon plants possessing aphid resistance were almost free from infection of virus mediated by aphids. By employing resistant cultivars, therefore, the necessity of insecticides could be minimized in cultivating melon.

As far as commercial use of PMAR No. 5 is concerned, it still has some serious problems due to its unacceptable characters for marketing in Japan: i.e. reddish flesh, low sugar contents, development of abscission layer on peduncle, and physiological leaf-withering. A breeding program is presently under way in Japan, through which several inbred lines have been derived from the hybrids between PMAR No. 5 and Japanese cultivars of an EARL'S FAVORITE type. Those inbred lines are characterized by a netted and green flesh type. However, further improvements are required to remove an undesirable character of leaf-withering. Since leaf-withering is genetically a recessive character, it is expected that this shortcoming could be easily alleviated in the breeding efforts. In fact, some of the F_1 hybrids, using those inbred lines as a parent, are promising for commercial use in the near future.

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