MORPHOLOGICAL AND COMMERCIAL CHARACTERS OF BRUSSELS SPROUT ANDROGENIC R₂/R₃ GENERATIONS AND EXPERIMENTAL F₁ HYBRIDS

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Summary

In the years of 2005-2007 twelve Brussels sprout androgenic lines of R₂ and R₃ generations derived from four commercial cultivars: Ajax F₁, Diablo F₁, Icarus F₁, Philemon F₁ were evaluated according to marketable yield, plant height, intraline uniformity and other morphological traits important for the breeding. In 2007 twelve single F₁ hybrids obtained by the use of androgenic lines were also evaluated in comparison to their parental components. Evaluation showed extended diversity of morphological (plant height, shape of the head, uniformity) and agroeconomical characters among the tested lines. Nine lines showed good intraline uniformity and stability in R₂ generation. After selection all tested lines of R₃ generation were uniform. Experimental F₁ hybrids showed intraline homogeneity, high yield similar to Diablo and Philemon F₁ control cultivars and morphological characters typical for good quality commercial Brussels sprout. Some level of inbreeding depression among androgenic lines was observed in comparison to their donor cultivars, while experimental F₁ hybrids showed significant effect of heterosis.

key words: Brussels sprout, androgenic lines, F₁ hybrids, breeding, morphological traits

INTRODUCTION

Genetic diversity of cabbage plants usually obtained with the use of traditional or biotechnological methods, including androgenesis, is necessary for the breeding purposes. The availability of microspore and anther culture techniques was previously described for *Brassica oleracea* crops such as head cabbage, broccoli, Brussels sprout and cauliflower (Chiang *et al.* 1985, Dore & Bouliard 1988, Ockendon 1986, 1988, Chauvin *et al.* 1993, Górecka *et al.* 1997, 1998, Farnham 1998, Kamiński *et al.* 1999a, 2004, 2005, Wang *et al.* 1999). However, there is a lack of information showing practical engagement of androgenic materials into a cabbage breeding program and it is very difficult to determine

which cabbage cultivars are based on androgenic parents. Anther and microspore culture is rarely used in cabbage breeding programs because it is difficult to establish breeding lines that are uniform and stable throughout consecutive generations. Lack of natural selection in the first stages of haploid development as well as gametoclonal and somaclonal variation among androgenic plants could have a negative influence on the quality of R_0 plants and their agronomic performance. Therefore doubled haploid (DH) lines often appear inferior in comparison to conventionally obtained inbred lines (Niemirowicz-Szczytt 1997, Kamiński *et al.* 1999a, 2004). Other factor that may decrease the effectiveness of the androgenic method is a relatively low number of R_1 seeds are created as well as diversified strength and stability of their self-incompatibility alleles (Chauvin *et al.* 1993, Hoser-Krauze 1993, Kamiński 2005, Ockendon 1973, Wallace 1979). In addition, an androgenic population derived from only one or few donors might be too narrow for obtaining a sufficient number of good quality and homozygous breeding lines. As an example, after multi-step selection of a large androgenic Brussels sprout population from Philemon F_1 hybrid, performed in R_0 and R_1 generations, only five lines with good morphological traits, useful for the further breeding remained (Kamiński *et al.* 2004, 2005).

Therefore, in this experiment a considerably larger number Brussels sprouts genotypes, was gathered to preserve a genetic diversity necessary for the breeding. The aim of this study was the evaluation of several morphological and commercial characters of the androgenic Brussels sprout R_2 and R_3 populations obtained from donor plant of four F_1 cultivars (Ajax, Diablo, Icarus and Philemon), and twelve single experimental F_1 hybrids performed in comparison to Philemon F_1 and Diablo F_1 according to commercial yield, plant height and heterosis.

MATERIAL AND METHODS

The use of androgenic material in the Brussels sprout breeding program at the Research Institute of Vegetable Crops began in 1996. First three androgenic R_0 populations from Ajax, Diablo and Icarus F_1 donor plants were derived in Tissue Culture Laboratory in the years of 1996-1998 and were transferred to Genetic and Breeding Department for their further selection (Krzyżanowska & Górecka 2004 a,b). Fourth androgenic population from Philemon F_1 hybrid were obtained in 2001 and described by Kamiński *et al.* 2004. Androgenic Brussels sprouts of R_0 generation was evaluated in the greenhouse for their ploidy level, morphological characters and self - incompatibility. The consecutive R_1 population derived from selected diploid R_0 androgenic plants was tested at the field according to their agro-economic traits in vegetative and generative stage (Kamiński *et al.* 2005). For obtaining of the next R_2 generation, androgenic Brussels sprout R_1 lines, recognized as suitable for the further breeding, were gathered from each of four donor cultivars and propagated by bud pollination in the greenhouse in 2004. In 2005, twelve Brussels sprout androgenic lines of R_2 generation obtained from Diablo F_1 (DA, DD, DE, DF),

Icarus F₁ (J13), Ajax F₁ (AH, AP) and from Philemon F₁ (P4, P5, P11, P14, P18) and two commercial F₁ cultivars (Diablo, Philemon) were evaluated at the field at the Research Institute of Vegetable Crops, Skierniewice. In 2006, the consecutive F₃ generation was derived from selected plants of R₂ pedigree with typical morphological characters and propagated at the greenhouse by the bud pollination. To create new F₁ hybrids, lines with strong and stable self-incompatibility were used as maternal components, while lines with tendency to set seeds at open pollination were used only as paternal components. Only uniform lines with desirable morphological traits and high vigor were used for crossing program. For higher level of heterosis, parental lines for single F₁ hybrids were always taken from different donor cultivars. Twelve single experimental F₁ hybrids (DA x AH, DD x AH, AP x P11, J13 x P11, DA x P4, P11 x DA, P5 x DF, DD x AP, P14 x J13, P5 x DE, P5 x J13 and DD x P5) obtained by cross-pollination with sufficient amount of seeds were used to set up an experiment in the field in 2007.

In both years of experiment (2005, 2007), the tested plants developed from seeds in the greenhouse in mid-May. One-month-old seedlings were planted in the field (spacing 50 cm x 60 cm) in a completely randomized block design with three replications. Each plot consisted of ten plants in one row. The soil type was a pseudopodsolic over loamy sand (1.5% organic matter, pH 6.5). Fertilization, pest and disease control followed the current recommendations. Plants were harvested gradually from the beginning of October to the end of November when sprouts reached maturity. Plant height, total and marketable yield per plot were measured. For the evaluation of heterosis effect, two pairs of F₁ hybrids – the best yielding (DD x P5) and with the lowest marketable yield from all tested (DA x AH) - were compared with their parental components and with their donors as a control. Results were subjected to an analysis of variance (ANOVA). The significance of differences among means was evaluated by Newman-Keul's test at P=0.05. The other morphological characters such as intraline uniformity, tendency to form a head, shape of stem, spacing between sprouts, petiole attitude, size, intensity of color, blistering and waxiness of leaf blade, density, shape and sprout size as well as a time of harvest maturity were classified separately for each plot using of the multi-grade IBPGR scale.

RESULTS

Both of analyzed factors: commercial yield and plant height of Brussels sprouts androgenic lines were reasonably higher in 2007 than in 2005 for almost all accessions (Fig. 1. A,B) due to the most favorable weather: lower temperatures and higher rainfalls during all season of vegetation in 2007.

Decreasing vitality caused by inbreeding depression was observed among Brussels sprout androgenic lines in comparison to both donor cultivars (Fig. 1. A,B). Most androgenic lines had lower marketable yield per plot than the mean value of cv. Diablo (4.98 kg) and Philemon (5.46 kg). One androgenic line, P5, obtained from Philemon F₁ donor cultivar was the tallest (90 cm) and had the greatest marketable yield (5.75 kg). The yield of P5 was comparable to com-

mercial F₁ hybrids. In contrast to P5, the second highest yielding androgenic line, DD, (4.44 kg) was from the lowest (66 cm) population tested. Three other lines (DA, DE and DF) derived from Diablo F₁ were also low and their yield of sprouts was relatively small. Two lines: AP and AH, derived from Ajax F₁ hybrid had the lowest marketable yield (1.92 kg and 1.64 kg) respectively. The single androgenic line, J13, obtained from Icarus F₁ had an average plant height similar to the mean of all accessions.

Fig. 1. Marketable yield (kg) (A) and mean plant height (cm) (B) per plot for Brussels sprout commercial F₁ hybrids and androgenic lines of R2 (2005) and R3 (2007) generations (Skierniewice 2005, 2007)

Each of the investigated Brussels sprout androgenic line was characterized by distinctive morphological characteristics that may allow for their identification among all other accessions (Table 1). Nine Brussels sprout androgenic lines of R_2 generation (DA, DD, DE, AH, AP, P4, P11, P5, P14) were uniform according to the all tested morphological traits. Three other lines (DF, J13 and P18) showed small but evident lack of uniformity for one of the twelve characters evaluated. Androgenic R_3 generation was more uniform for all tested lines probably due to the strict selection of the most characteristic R_2 plants taken for the generative propagation in 2006. Two lines (AP, P11) as well as both control F_1 cultivars, created medium – size heads. Lines obtained from Diablo F_1 hybrid were characteristic of their donor. They had conical (DA, DD, DF) or slightly conical (DE) shaped stems with small (DA, DD, DE) or medium (DF) spacing between sprouts. Androgenic lines from Icarus, Ajax and Philemon F_1 hybrids were rather cylindrical. Four androgenic lines (P18, P11, P5 and P14) and Philemon F_1 had a large spacing between sprouts while all other lines and experimental F_1 hybrids had small or medium spacing.

Lines DA, J13, P11 and P14 had semi – erect petioles and the rest were horizontal. Characteristics of leaf blade shape of Brussels sprout R_2 and R_3 generations also showed a high level of diversity. Most of accessions had small leaf blades with the exception of Philemon F_1 and four of their pedigrees (P4, P18, P11, P14). Lines DF and J13 were characterized by a darker color leaf blade than control cultivars and three of them, DA, P18, were lighter. Five lines had atypical medium (DA, DD, DE and J13) or strong (DF) blistering of leaf blade. Lines DA, DF and AH had smaller waxiness of the leaves than other accessions.

Three lines had medium (DF, P4) or loose (P5) sprouts while all control and experimental F_1 hybrids were dense. Most of the lines had a broad obovate and circular shaped sprouts except the DA line had untypical narrow - obovate sprouts. Three lines (AH, AP, and P14) had smaller sprouts and very late time of harvest maturity. Line DD was the earliest of all tested, while three other lines (DA, DE, DF) reached their maturity at the same time as Diablo F_1 . In contrast, J13 and other lines from Ajax and Philemon F_1 were late to very late (Table 1).

Experimental Brussels sprout F_1 hybrids had good morphological characters and uniformity typical for commercial F_1 cultivars (Diablo and Philemon) used as a control. However, they differed significantly according to marketable yield and plant height (Fig. 2. A,B). Three F_1 hybrids: DA x AH (4.03 kg), DD x AH (4.15 kg) and AP x P11 (4.29 kg) had lower commercial yield than Diablo (5.13 kg) and Philemon (5.46 kg). Four crosses (J13 x P11, DA x P4, P11 x DA and P5 x DF) were at the same level as two control cultivars, while other experimental F_1 hybrids: DD x AP (7.28 kg), P14 x J13 (7.28 kg), P5 x DE (7.30 kg), P5 x J13 (7.99 kg) and DD x P5 (9.31 kg) had significantly higher crop. Two control F_1 hybrids were significantly different from each other according to the mean plant height: Diablo (76 cm), Philemon (95 cm). Only four experimental F_1 cultivars: DD x AH (100 cm), P5 x DF (101 cm), DD x P5 (102 cm) and P5 x DE (107 cm) were higher than Philemon F_1 .

Table 1. Morphological traits of Brussels sprout androgenic lines and F₁ hybrids in vegetative phase, Skierniewice 2005, 2007

Androgenic line /F ₁ hybrid	Intraline uniformity * ₁	Plant		Stem		Petiole		Leaf blade			Sprout		Time of harvest maturity * ₁₃
		Tendency to form a head * ₂	Shape with sprouts * ₃	Spacing between sprouts * ₄	Attitude * ₅	Size * ₆	Intensity of color * ₇	Blistering * ₈	Waxiness * ₉	Density * ₁₀	Shape * ₁₁	Size * ₁₂	
DA	1	3	1	3	3	3	3	5	3	7	1	5	3
DD	1	3	1	3	5	3	5	5	5	7	2	5	1
DE	1	3	2	3	5	3	5	5	7	7	3	5	3
DF	2	3	1	5	5	3	7	7	3	5	2	5	3
J13	2	3	3	5	3	3	7	5	7	7	2	5	5
AH	1	9	3	5	5	3	5	3	3	7	3	3	9
AP	1	5	3	5	5	3	5	3	5	7	3	3	9
P4	1	3	3	5	5	5	5	3	7	5	2	5	7
P18	2	3	3	7	5	5	3	3	5	7	2	5	7
P11	1	5	3	7	3	5	5	3	5	7	3	5	7
P5	1	3	3	7	5	3	5	3	5	3	2	7	7
P14	1	3	3	7	3	5	5	3	7	7	3	3	9
Diablo F ₁	1	5	1	5	3	3	5	3	5	7	2	7	3
Philemon F ₁	1	5	3	7	3	5	5	3	7	7	3	5	7

Multigrade scale of Brussels sprouts morphological characters in generative phase:

#1 Intraline uniformity	1 – uniform,	2 – slightly diversified,	3 – diversified
#2 Tendency to form a head	3 – weak,	5 – medium,	7 – strong
#3 Shape of stem with sprouts	1 – conical,	2 – slightly conical,	3 – cylindrical
#4 Spacing between sprouts	3 – small,	5 – medium,	7 – large
#5 Petiole: attitude	3 – semi-erect,	5 – horizontal,	7 – drooping
#6 Leaf blade size	3 – small,	5 – medium,	7 – large
#7 Intensity of color	3 – light,	5 – medium,	7 – dark
#8 Leaf blistering	3 – weak,	5 – medium,	7 – strong
#9 Leaf waxiness	3 – weak,	5 – medium,	7 – strong
#10 Sprout density	3 – loose,	5 – medium,	7 – dense
#11 Sprout shape	1 – narrow obovate,	2 – broad obovate,	3 – circular
#12 Sprout size	3 – small,	5 – medium,	7 – large
#13 Time of harvest maturity	1 – very early,	3 – early,	5 – medium, 7 – late, 9 – very late

Fig. 2. Marketable yield (kg) (A) and mean plant height (cm) (B) per plot for brussels sprout experimental and commercial F₁ hybrids (2007)

Heterosis for marketable yield was observed among selected F₁ hybrids. Both of them: DD x P5 (9.31 kg) and DA x AH (4.03 kg) had significantly higher commercial yield than their parental components: DD (4.46 kg), P5 (5.88 kg), DA (2.7 kg) and AH (1.73 kg) (Fig. 3. A,B). Marketable crop of the best yielded experimental F₁ hybrid DD x P5 exceed also values for both of donor cultivars: Diablo F₁ (5.13 kg) and Philemon F₁ (5.46 kg), while DA x AH F₁ hybrid had significantly lower yield than Diablo.

Fig. 3. Heterosis effect for marketable yield (kg) of selected brussels sprout experimental F₁ hybrids (A,B) in comparison to their androgenic parental components and donor cultivars (2007)

DISCUSSION

Evaluation of androgenic Brussels sprout R₂ and R₃ generations derived from donor plant of four cultivars showed extended diversity of morphological and agroeconomic characters among all tested accessions. Interline variation between androgenic lines obtained from different donor plant of cultivars was evidently higher than among the lines from the same donor. These results are supported by phenotypic observations (Kamiński *et al.* 1999b) showing the level of variation among DH lines of three head cabbage cultivars in R₁ generation. Genetic diversity among the tested lines resulted in a high level of heterosis in terms of commercial yield and plant height for the most of their experimental F₁ hybrids. The existence of inbreeding depression among androgenic Brussels sprout lines and increasing vigor caused by the effect of heterosis for their F₁ cultivars were also characteristic for the androgenic head cabbage lines and F₁ hybrids (Kamiński 2000, 2001). The lower level of intraline uniformity among three Brussels sprout lines of R₂ generation (DF, J13, P18) might be caused by the environmental or genetic factors. Molecular analysis with the use of DNA markers shall alleviate some of the confusion associated with morphological characteristics of androgenic lines (Kamiński *et al.* 2003) before they will be used for the further breeding. However it was possible to improve uniformity through selection of plants with typical characteristic performed in vegetative and generative phase for each of androgenic line in previous generations. Generally, the quality of the R₃ and R₂ generations was relatively better than in R₀ and R₁ androgenic populations from Philemon F₁ hybrid described by Kamiński *et al.* 2004, 2005. Lines with good intraline uniformity and stability in R₂ and R₃ generations might be useful for breeding purposes. In further investigations, androgenic lines should also be assessed taking into consideration the number of self - incompatibility alleles as well as their activity, dominance, stability (Hodgkin 1981, Johnson & Blyton-Conway 1976, Ockendon 1973) and their practical consequences for the F₁ hybrids development. The obtained re-

sults suggests that selection of diversified androgenic lines of Brussels sprout during several generations with good morphological trait and stability can be a method for developing vigorous and uniform F₁ hybrids which may be more productive and attractive than their donor cultivars.

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CECHY MORFOLOGICZNE I UŻYTKOWE ANDROGENICZNYCH LINII
POKOŁENIA R_2 , R_3 ORAZ EKSPERYMENTALNYCH MIESZAŃCÓW F_1
KAPUSTY BRUKSELSKIEJ

Streszczenie

W latach 2005 i 2007 dwanaście androgenicznych linii kapusty brukselskiej pokolenia R_2 i R_3 , otrzymanych z czterech odmian (Ajax F_1 , Diablo F_1 , Icarus F_1 i Philemon F_1), oceniono w doświadczeniu polowym pod względem plonowania, wysokości roślin, wyrównania wewnątrzliniowego oraz cech morfologicznych (wysokość roślin, kształt główek, wyrównanie) istotnych dla hodowli. W 2007 roku oceniono również dwanaście pojedynczych mieszańców F_1 otrzymanych w oparciu o androgeniczny materiał. Wykazano duże zróżnicowanie cech morfologicznych i użytkowych badanych linii. Dziewięć androgenicznych linii cechowało się zarówno dobrą jakością, wyrównaniem wewnątrzliniowym oraz stabilnością w pokoleniu R_2 . W wyniku przeprowadzonej selekcji linie pokolenia R_3 były wyrównane. Eksperymentalne mieszańce F_1 charakteryzowały się dobrym wyrównaniem, wysokim plonem, porównywalnym z odmianą Diablo F_1 i Philemon F_1 oraz cechami morfologicznymi typowymi dla dobrej jakości komercyjnych odmian kapusty brukselskiej. Większość androgenicznych linii charakteryzowała się depresją wsobną w porównaniu do roślin donorowych, podczas gdy eksperymentalne mieszańce F_1 wykazywały istotny poziom heterozji.