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ORIGINAL PAPER

Field evaluation of doubled haploid plants in the *Apiaceae*: dill (*Anethum graveolens* L.), caraway (*Carum carvi* L.), and fennel (*Foeniculum vulgare* Mill.)

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Abstract The *Apiaceae* family includes vegetables, as well as herb and spice crops. Compared to major crops, there have been few breeding or genetic improvement programs for any of the *Apiaceae*, especially the herb and spice species. Haploidy technology can be used to develop uniform, true-breeding lines, as well as to accelerate breeding programs. Field trials of dill (*Anethum graveolens* L.), caraway (*Carum carvi* L.), and fennel (*Foeniculum vulgare* Mill.) doubled haploid (DH) lines were conducted over 2–5 cropping seasons. Several of the DH dill lines had desirable agronomic characteristics such as short uniform stature along with early maturity that would be useful for crop improvement. Seed yields and the essential oil content of the seed harvested from the best performing DH dill lines were either equal to or higher than the parental line. A DH annual caraway line was identified that produced higher seed yields than the industry standard. The main constituents of the essential oil for the DH lines of both dill and caraway were similar to the parental lines. Fennel DH lines exhibited differences in height but were too late in maturity for seed production under prairie conditions. The results indicate that not only were we able to generate DH lines that could be used in a crop improvement program, but we developed DH lines that could be used directly as cultivars as these lines performed better than the industry standard (parental line).

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Introduction

The *Apiaceae* include a number of economically important vegetable, herb, and spice crops used as food, flavourings, perfumes, cosmetics, and medicinals for humans and animals (French 1971). They are grown worldwide, but are most common in the temperate regions of the northern hemisphere. There is an economic need to develop new cultivars of *Apiaceae* species better suited to Canadian prairie conditions. Earlier maturity coupled with increased yields of fruit (commonly known as seed), higher seed oil content, and better oil quality are the main objectives of improvement programs for *Apiaceae*.

Dill (*Anethum graveolens* L.) is an annual or biennial herb used primarily as a condiment. Dill seed and leaves are used as flavouring in sauces, vinegars, pastries, and soups. Dill has medicinal value as a diuretic, stimulant, and a carminative (Peirce 1999). The main constituents of the oil extracted from dill seed are D-carvone (35–60%) and D-limonene (35–50%) (Weiss 2002). Caraway (*Carum carvi* L.) is an annual or biennial herb native to Europe or western Asia. Caraway seed is used whole as a spice or crushed to produce caraway oil. The seeds have a licorice flavour and are used in breads, soups, spreads, salad dressings, and liqueurs. The leaves can be used in cooking, as can the roots. Caraway seed and seed oil have medicinal applications for disorders such as rheumatism, eye infections, toothaches, and nausea (Peirce 1999). The main constituents of the seed oil of caraway are similar to dill with D-carvone (45–60%) and D-limonene (35–55%)

(Weiss 2002). Carvone has been used as a flavour additive in foods, a sprouting inhibitor for potatoes (Beveridge et al. 1981), a growth inhibitor for fungi (Smid et al. 1995) and bacteria (Helander et al. 1998; Oosterhaven et al. 1996) and as an insect repellent (Salom et al. 1996; Lee et al. 1997). The oil can also be used as a fragrance component in cosmetics (e.g., soaps, creams, lotions, and perfumes). Fennel is an erect, umbelliferous herb of the same family (French 1971). There are three subspecies of *Foeniculum vulgare* ssp. c*apillaceum: azoricum*, also known as bulb fennel, Italian fennel, or Florence fennel; *dulce*, also known as sweet fennel, French fennel, or oilseed fennel; and *vulgare* (bitter fennel), which is perennial, and has an essential oil content higher than that of *dulce*. Bulb fennel is used as a vegetable, whereas sweet fennel is used as a condiment. Fennel seed is used in the food industry to flavour meats, vegetables, fish, soups, salad dressings, stews, breads, pastries, teas, and alcoholic beverages. Trans-anethole is the dominant component in the essential oil extracted from fennel seeds (Weiss 2002). This oil is used in condiments, soaps, creams, and perfumes. The medicinal or nutraceutical applications of fennel include use as an antispasmodic, carminative, diuretic, expectorant, laxative, and stomachic (Peirce 1999).

Doubled haploid (DH) technologies, to produce embryos/plants from haploid immature pollen grains (microspores), are being used around the world to develop new cultivars and uniform lines in many plant species (Thomas et al. 2003). The main advantage to plant breeders of using doubled haploid breeding lines is the reduction in time required to achieve homozygosity. True-breeding lines can be generated in one generation rather than several years of backcrossing or selfing. This is also beneficial for producers and consumers as high yielding cultivars with improved agronomic and quality traits can be developed more rapidly.

The objective of this project was to compare the agronomic performance of DH dill, caraway, and fennel lines derived via microspore culture against their corresponding parental lines under field conditions.

Materials and methods

The DH lines were derived from locally adapted cultivars using the doubled haploidy methodology outlined in Ferrie et al. (2010). As seed supply of the DH lines was limited, lines were initially grown in small plot non-replicated trials. The seed obtained from these trials was used in subsequent larger scale replicated trials.

The agronomic characteristics of the DH lines were evaluated in field trials conducted at the University of Saskatchewan Horticulture Research Facility in Saskatoon, Saskatchewan, Canada. Unless otherwise specified, the crops were managed using standard commercial production practices. Soil fertility in the plot area was adjusted prior to planting to meet industry recommendations. Weeds were controlled using tillage and herbicides. The plots were only irrigated under extreme drought conditions to improve crop emergence or as required to activate soil-applied herbicides. No insect or disease control measures were employed.

Dill

A total of 41 DH lines of dill were evaluated from 2003 to 2008. Any DH line with poor seed viability (<20% germination) was eliminated from further field testing. In 2003, viable seed of 12 DH lines was available to conduct a field trial. Due to the limited seed supply and unknown vigor of the DH lines, the seedlings were initially grown for 6 weeks under greenhouse conditions before being moved to the field. The seedlings were planted out in the field in late May in rows spaced 0.5 m apart, with 15 cm between plants within the row. Seedlings of the parental line ('Mammoth') were included in this trial for comparison purposes. In 2004, the DH dill lines that had produced the most complete stand and the highest seed yields in the 2003 field trial were evaluated in a direct-seeded field trial that again included the parental line. This trial was initiated using seed harvested from the field trial conducted in the previous year. The trial was planted in mid-May using a small plot seeder. Each plot consisted of four 8 m long rows of each DH line. The trial was laid out in a randomized complete block design with three replicates. Seed was harvested as each line matured using a small plot combine. The 2005 trial was lost to flooding. Field evaluations were repeated in 2006, 2007, and 2008 using the same procedures, except in 2007 when each line was chemically desiccated with diquat (Reglone) applied at 2.2 l/ha as soon as the line began to mature. The lines were hand swathed 5 days later, allowed to dry in the field for 1 week, and then combined as previously described. This modification to the harvest method was implemented in an effort to reduce the shattering losses that occur as the dill crop begins to ripen.

In each year of testing, the DH lines and the parental line were compared for time of bloom, plant height at maturity, seed yields, seed oil content, and the relative amounts of the main constituents in the oil.

Caraway

A total of 25 DH lines of annual-type caraway and three parental lines (NN-1, NN-2, and Moran) were available for field testing, beginning in 2006. As with dill, the first year of testing of caraway involved a limited number of plants established as transplants in a non-replicated trial. The

4-week old transplants were set out in rows spaced 0.5 m apart with 15 cm between plants within each row. The trial was hand-harvested in early October and threshed using a stationary combine. Because of the highly variable numbers of plants for each line, no yield comparisons were possible in 2006.

The three DH caraway lines that had produced significant quantities of seed in the 2006 trial were evaluated in a replicated direct-seeded field trial in 2007 and 2008. These trials were planted and maintained as described in the dill trial. The trials were chemically desiccated in early October at which time all of the lines were still growing vigorously. Due to the short stature of the caraway plants, they had to be hand harvested and then threshed using a stationary combine.

Fennel

The fennel trials were conducted in 2003 and 2004. Due to limited seed supplies, all lines were grown from transplants rather than by direct seeding. In late May, six-week old fennel seedlings were transplanted into the field. Plants for each line were spaced 30 cm apart within the row, with 50 cm between rows. Each line was grown in a single 10 m long row. In the 2003 trial, 14 DH oilseed fennel lines were evaluated, along with the parental line. In 2004, another 11 DH oilseed fennel lines were evaluated along with the parental line. Germination percentages and plant heights were recorded. In both years, the growing season was too short to allow development of seed in any of the fennel lines tested.

Chemical analyses: dill and caraway

Essential oils were extracted from the harvested seed of dill and caraway by hydro-distillation using a Clevenger-type apparatus. Five grams of clean seed was ground for 40 s in a Krups coffee grinder, transferred into a 1,000 ml round bottom flask, after which 500 ml distilled water was added. Distillation was allowed to proceed for 2 h after the first few drops of distillate were obtained. After cooling the apparatus for 20 min, the length of the essential oil column in the side-arm of the Clevenger apparatus was measured and the volume of essential oil calculated. The results are expressed in percent essential oil (v/w) based on the weight of the air-dried seed. The oil was stored at −18°C in the dark prior to subsequent chromatographic analysis.

A Hewlett-Packard gas chromatograph (Series Model 5880A) equipped with a flame ionization detector and a capillary column containing 95% dimethyl-5% diphenyl polysiloxane (DB-5; 10 m × 0.25 mm i.d.; film thickness: 0.25 μm; J&W Scientific, Folsom, CA) was used. Helium was the carrier gas with a column inlet pressure of 2.1 kg/cm^2. The injector and detector temperatures were set at 275 and 300°C, respectively. The oven temperature was programmed as follows: [a] initial temperature: 75°C; [b] initial time: 5.0 min; [c] program rate: 8°C/min; [d] final temperature: 200°C; and [e] final time: 2 min.

Ten microliters of essential oil were diluted to 500 μl with chromatographic grade hexane prior to gas chromatography. One microliter was injected at a split ratio of 1:50. The individual peak areas were quantified using a Hewlett-Packard 3396 Series II integrator with a chart speed of 1.0 cm/min and an attenuation of 2. The retention times of the compounds of interest, carvone and limonene, were compared to the retention times of a pure carvone and limonene standard runs under identical conditions. The results were expressed as a percentage of the total peak area.

Statistical analysis

All data from the replicated trials were analyzed using analysis of variance procedures. Where significant ($P < 0.05$) F-test values were observed, means were compared using Fishers protected least significant difference test ($P < 0.05$).

Results and discussion

Dill

The presently available commercial dill lines have an indeterminate growth habit resulting in uneven crop maturity and challenging harvest conditions. With highly indeterminate seed set, it is inevitable that a portion of the dill seed is lost to shattering before the crop is ready to harvest, while another portion of the seed is still immature at harvest. Immature dill seed does not have the oil content or flavor profile required by the industry. The development of an early, uniform-maturing dill line would be beneficial for producers.

For 23 of the 41 DH dill lines tested, seed viability was extremely low (<20%) and those lines were eliminated from further testing (data not shown). A few of the DH lines showed a moderate degree of reduction of seed viability (40–60% germination) relative to the parental line (>90% germination). The poor germination rates of these lines limited their yield potential and these lines were also removed from the trial. The germination rates of the remaining DH lines were comparable to the parental line in all years of testing.

Differences in plant height at maturity were observed between the parental line and the dill DH lines. Over 4 years (2003, 2004, 2006, 2007), five of the DH lines

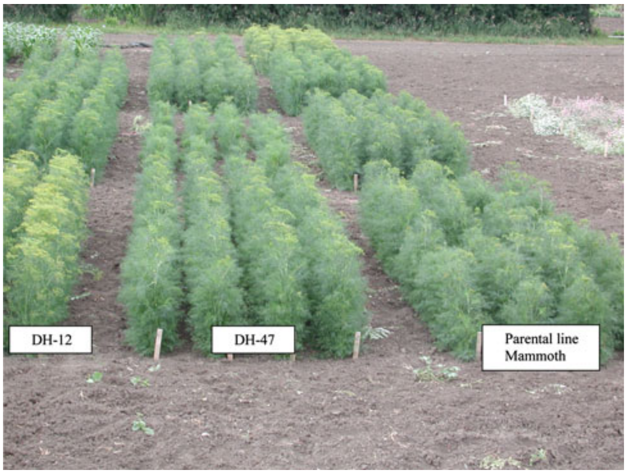

Fig. 1 Doubled haploid dill lines and parental line grown under field conditions in 2007

(DH-7, DH-12, DH-35, DH-45, DH-47) were shorter than the parental cultivar Mammoth by 12–32%. Two lines (DH-1, DH-53) were similar in height to the parental cultivar. Irrespective of the average height, the DH lines were more uniform in stature than the parental line (Fig. 1). The height of the umbels in the DH dill lines also tended to be more uniform than in the parental line, which should improve the efficiency of mechanical harvesting. The shorter stature DH lines could be useful in situations where lodging leads to harvest problems; however, a taller stature might indicate greater yield potential if the leafy portion of the crop were destined for processing as dill weed. The dill doubled haploid line DH-1 is a very vegetative plant with large seeds. Seed production by this line was low because of the late maturity (Table 1), and the vegetative growth of the plant. This line might prove useful for dill weed and/or dill weed oil production, however the yield and oil content of the leaves were not analyzed in this project. This line was not evaluated in 2007 and 2008 because of the low seed yield. Our selection focus was on early maturing lines with high seed yield.

Table 1 Percent flowering of dill (*Anethum graveolens* L.) doubled haploids (DH) and parental line (cv. Mammoth) in 2006, 2007, and 2008

Line	July 20, 2006	July 18, 2007	July 28, 2008
DH-1	25 d*	NA	NA
DH-7	12 ef	0 a	0 b
DH-12	100 a	5 a	60 a
DH-35	15 de	0 a	10 b
DH-45	47 c	0 a	5 b
DH-47	10 ef	0 a	15 b
DH-53	3 f	0 a	0 b
Mammoth	78 b	2 a	18 b

* Values within columns followed by the same letter are not significantly different based on Fishers protected LSD test ($P < 0.05$)

NA line not tested

Differences were observed among the DH dill lines and the parental cultivar for date of flowering. On July 20, 2006, DH-12 was in full bloom, whereas most of the other lines were just starting to flower (3% flowering with DH-53 to 47% flowering in DH-45; Table 1). The parental line was 78% flowering. There was year to year variation in time of flowering. On July 18, 2007, only two lines had started flowering, DH-12 and the parental line. In 2008, 60% of DH-12 was flowering, whereas other lines had not begun to flower (DH-7, DH-53), even though data was collected 8–10 days later than the previous years (Table 1). Early flowering and early maturity are beneficial for prairie climatic conditions, however it can also be detrimental as the earlier flowering lines appeared more prone to infection with blossom blight, as was the situation in 2006. As a consequence of this disease, many of the seeds were shrunken or non-viable.

Relative seed yield of the DH dill lines, compared to the parental line, varied from year to year. In 2003, seed yields from the most productive DH lines (DH-7, DH-12, DH-35, and DH-45) were on average 61% higher than for the parental line (data not shown). In 2004, seed yields of DH-12 were far higher than the parental line (350% of Mammoth), with DH-35 also producing a high yield (139% of Mammoth) (data not shown). A frost in mid-August of 2004 severely damaged the later maturing DH lines, as well as the parental line. Both DH-12 and DH-35 are relatively early maturing, and they largely avoided the damaging effects of the frost. In 2006, several of the DH lines again had seed yields that were similar to or greater than the parental line; however, seed yields for DH-12 were poor in 2006 as this line was severely infested with blossom blight (Table 2). Seed yields in the 2007 trial were almost 10 fold higher than in previous years, indicating the magnitude of shattering loss that occurred when the dill was directly combined. None of the DH lines had seed yields that exceeded the parental line in 2007, although yields for DH-7, DH-12, and DH-35 were not significantly different from the parental line. The combination of more careful harvest management practices, coupled with near ideal conditions through the fall of 2007 was advantageous to the relatively late maturing parental line. In 2008, DH-35 was the highest yielding line and was ready to harvest 1 week before the parental line. DH-12 also produced a yield which exceeded Mammoth in 2008 and it was ready to harvest 2 weeks earlier than the parental line. In years with an earlier or less favorable fall, the earlier maturing DH lines would likely produce better yields and as the seeds would be more mature, higher oil content would be expected. Over the 3 years of replicated trials, DH-12 and DH-35 had an average seed yield greater than the parental

Table 2 Seed yields, seed oil concentration, and main oil components for doubled haploid (DH) and parental line (cv. Mammoth) of dill (*Anethum graveolens* L.) from 2006 to 2008

DH line or parent	Seed yield (kg/ha)			Essential oil concentration (% v/w)			Carvone (%) [limonene (%)]		
	2006	2007	2008	2006	2007	2008	2006	2007	2008
DH-7	640 ab*	2750 ab	2000 d	2.7 c	3.0 a	2.2 b	39.9 d [52.6 a]	40.1 c [54.8 a]	34.7 c [65.3 a]
DH-12	142 de	2851 ab	3110 a	3.7 a	2.8 a	3.1 a	43.7 abc [50.3 ab]	43.7 ab [53.9 ab]	39.7 b [60.3 b]
DH-35	485 bc	2962 a	3360 a	2.3 d	2.9 a	2.5 ab	42.9 bc [50.3 ab]	44.0 ab [52.2 bcd]	42.3 ab [57.7 bc]
DH-45	339 cd	2357 c	2700 bc	2.2 d	2.8 a	2.2 b	46.0 a [47.6 c]	44.3 ab [52.5 bcd]	44.5 a [55.5 c]
DH-47	59 e	1412 d	3040 ab	2.2 d	3.1 a	2.6 ab	41.2 cd [52.2 a]	45.3 ab [51.8 cd]	42.8 a [57.2 bc]
DH-53	774 a	2616 b	1890 d	3.0 bc	3.1 a	2.5 ab	45.8 a [49.0 bc]	43.6 b [53.4 abc]	40.8 ab [59.2 bc]
Mammoth	352 cd	3136 a	2280 cd	3.1 b	2.8 a	2.5 ab	45.0 ab [50.3 ab]	46.0 a [50.5 ab]	41.8 ab [58.2 bc]

* Values within columns followed by the same letter are not significantly different based on Fishers protected LSD test ($P < 0.05$)

line. The seed yields obtained in these experiments were substantially greater than those obtained in previous studies. Bailer et al. (2001) reported yields of 400–600 kg/ha in 1 year and less than 200 kg/ha in another year. These low yields were due to seed shattering, a common problem with dill cultivars. A uniformly maturing line would alleviate some of the seed shattering associated with this species.

Essential oil content of dill seed typically ranges from 1.2 to 7.7%, depending on the variety, growing conditions, and method of oil extraction (Weiss 2002). In Canada, seed oil content for dill typically ranges from 2 to 4%. Seed oil content of the DH dill lines evaluated in this project ranged from 2.2 to 3.7% over 3 years of replicated testing (2006–2008), with limited year to year variability in the oil content (Table 2). Over the 3 years, DH-12 consistently had similar or greater percent essential oil content compared to the parental line Mammoth. For most lines, the seed oil contained about equal amounts of carvone and limonene (Table 2) and this ratio was also consistent across production years. The North American dill seed oil industry is based on carvone content and stipulates that dill oil must contain at least 30% carvone; all DH dill lines tested in this trial exceeded this standard.

Caraway

In western Canada, caraway is typically grown as a biennial crop, as the growing season is too short for most presently available annual-type lines. The current annual types mature in about 120–130 days. Growing caraway as a biennial effectively ties up the field for two seasons, at significant cost to the grower. If annual types suited to short seasons were to become available they would represent a means to double the growers' land use efficiency.

A total of 25 DH lines and three parental lines of annual-type caraway were evaluated in field trials conducted in 2006. Seed viability was poor for most DH lines, with only three of the DH lines (DH-10, DH-21, and DH-29) showing more than 25% emergence of the planted seed. However, it should be noted that the parental lines also had poor emergence percentages resulting in poor stand (Table 3). In 2007, the only DH caraway seed available for larger scale field trials was from the three DH lines that had performed relatively well in 2006. In both the 2006 and 2007 trials, DH-10 produced a better stand than its parent (NN-2; Table 3).

Table 3 Field performance of DH annual caraway (*Carum carvi* L.) lines tested in 2006, 2007, and 2008

Line	Parental line	% Stand		Seed yield (kg/ha)	
		2006	2007	2007	2008
DH-10	NN-2	100	64	1184 a*	1080 a
DH-21	Moran	28	8	41 d	NA
DH-29	NN-2	78	50	488 b	670 b
Parental	NN-2	36	40	270 c	920 ab
Parental	Moran	20	43	187 c	740 b

* Values within columns followed by the same letter are not significantly different based on Fishers protected LSD test ($P < 0.05$)

NA line not tested

In mid-June 2007, a problem with aster yellows disease developed in the DH caraway plots. The extent of the infection and the impact on the plants was much more severe than in adjacent plots of DH dill. None of the infected caraway plants survived to produce seed and consequently, seed yields were potentially compromised. There did not appear to be any significant difference in the incidence or impact of aster yellows on the various DH lines or the parental lines of caraway.

Given the limited stand and the problems with aster yellows, seed yields were still unexpectedly high in the 2007 trial (Table 3). DH-10 produced 500% more seed than its parental line (NN-2) in 2007. In 2008, DH-10 again outperformed the parental line. Seed of DH-10 is substantially smaller than the seed of any of the other DH lines

Table 4 Seed oil concentration and main oil components for caraway (*Carum carvi* L.) DH lines and their corresponding parental lines

DH line	Parent	Essential oil concentration (% v/w)			Carvone (%) [limonene (%)]		
		2006	2007	2008	2006	2007	2008
DH10	NN-2	1.29	3.06 bc*	3.81 a	51.4 [42.6]	41.5 a [56.7 a]	32.4 a [67.6 a]
DH21	Moran	2.38	2.77 c	NA	47.5 [47.2]	39.7 a [57.5a]	NA
DH29	NN-2	0.69	3.16 b	3.65 a	31.8 [51.1]	40.3 a [57.4 a]	30.8 a [69.1 a]
Parental	NN-2	1.42	3.09 bc	2.86 a	51.5 [42.7]	43.1 a [53.3 a]	33.2 a [66.8 a]
Parental	Moran	1.51	3.70 a	3.43 a	49.3 [48.5]	39.1 a [53.1 a]	34.7 a [65.3 a]

* Values within columns followed by the same letter are not significantly different based on Fishers protected LSD test ($P < 0.05$)

NA line not tested

or the parental lines (data not shown). This may be undesirable for direct sales to the consumer where large seed size is equated with quality, however seed size would be of little importance to the processing sector.

Essential oil content of annual caraway seed typically ranges from 1.5 to 5.0%, depending on the variety, growing conditions, and method of oil extraction (Weiss 2002). The seed oil content of the caraway DH lines was much higher in 2007 and 2008 than in 2006 (Table 4); this likely reflects the fact that the crop was allowed to mature late into the fall of 2007 and 2008. The seed oil content of the parental line Moran was higher than any of the DH lines in 2007, however, this was not the case in 2006 or 2008. Over 90% of caraway seed oil consists of two monoterpenes, carvone and limonene. For the caraway DH lines, the ratio of carvone to limonene varied more between years than between lines in a given year. In Saskatchewan, carvone levels are around 46–50% in annual caraway and 54–57% in biennial caraway (Arganosa et al. 1998). This can also vary according to the genotype, seeding date, and location. Our DH lines show a lower carvone content, however the parental lines were also similar. The industry prefers caraway oil to have a higher carvone content (50–60%) (Weiss 2002) than was observed in any lines tested in this trial, including the parental lines. Carvone content increases as the seed ripens, and consequently, biennial types of caraway tend to have a higher carvone percentage than the annual types used in this project.

Fennel

In both 2003 and 2004, seed germination of the DH lines of oilseed fennel was quite variable. In 2003, four of the 14 lines were non-viable, while in 2004, five of the 11 lines tested did not germinate. Of the 16 viable DH lines (10 lines from 2003 and 6 lines from 2004), five had 100% germination while the germination percentages of the other lines varied from 25 to 60% (data not shown). The parental line consistently had a high germination percentage (95–100%).

There was significant variation from line to line in plant height of the fennel at the end of the growing season (ca 120 days after planting). In 2003, two of the DH fennel lines (DH-37 and DH-90) were approximately twice the height of the parental line (60 cm; Fig. 2a). The heights of the DH lines tested in 2004 more closely resembled the parental lines (Fig. 2b). Within the DH lines, plant heights were more uniform than the parental material, likely reflecting the genetic homogeneity characteristic of DH. Aside from differences in height, the morphology and rate of development of the DH fennel lines were similar to the parental line. In both years, the growing season was too short to allow development of seed in any of the fennel lines tested.

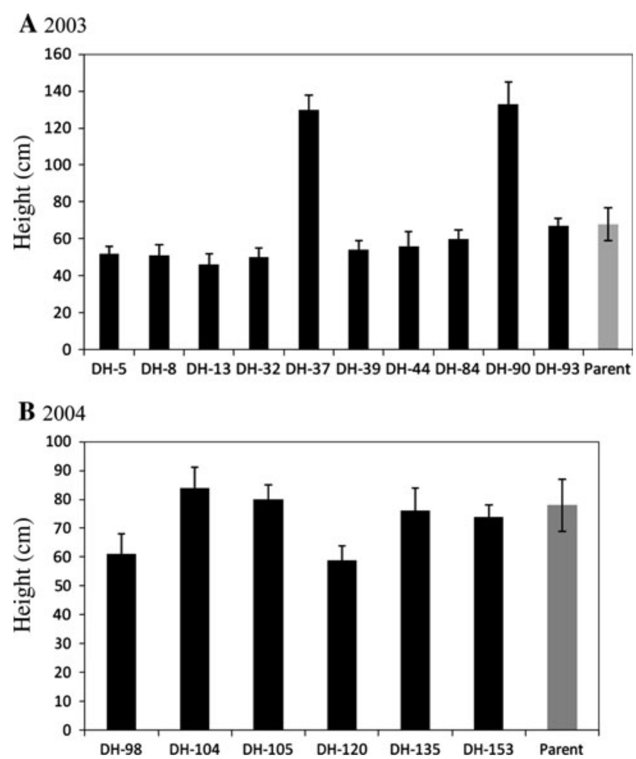

Fig. 2 Height (cm) of doubled haploid fennel (*Foeniculum vulgare* Mill.) lines grown in 2003 (**a**) and 2004 (**b**). *Vertical bars* represent standards errors ($n = 20$)

Conclusion

The *Apiaceae* species have been considered recalcitrant when it comes to androgenesis, especially microspore culture. Very little research has been published in this area and there were no efficient protocols available for generating doubled haploids prior to the methods developed by Ferrie et al. (2005, 2010). The objective of this project was to compare the agronomic performance of DH lines of dill, caraway, and fennel relative to the parental lines, while also surveying the DH material for traits that could be useful in subsequent crop improvement. Field comparisons of DH lines and their parental controls have not been previously reported in the *Apiaceae*, but there are reports in the *Brassica* species and barley (*Hordeum vulgare*) (Park et al. 1976; Friedt and Foroughi-Wehr 1983; Powell et al. 1986). In those species differences were observed between the DH lines and the parental line for a number of characteristics (e.g. yield, height, maturity). Generally, the DH lines were inferior (Palmer et al. 1996), but superior lines could be identified (Friedt and Foroughi-Wehr 1983). In our study, a significant proportion of the DH lines of dill, caraway, and fennel proved to have limited seed viability. Generally, this has not been observed in DH lines of other species. However, many of the *Apiaceae* DH lines that were viable showed promise in field trials. DH lines of dill were identified that were earlier maturing, more uniform in stature, and higher yielding than the parental lines. A single DH line of caraway with exceptional yield potential was also identified. Seed oil content and composition of the DH lines of dill and caraway were generally comparable to the parental lines, suggesting that the improvement in field performance was achieved without compromising crop quality. Our results show that *Apiaceae* doubled haploidy techniques can generate lines that have the potential for commercial production as well as lines that can be incorporated into a breeding program. Further efforts to create and characterize DH lines of dill and caraway with superior agronomic or quality characteristics are ongoing.

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