Essential Oil Yields and Quality of Fennel Grown in Nova Scotia

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Abstract. Field and laboratory experiments were conducted at two sites in Nova Scotia during 2001 and 2002 to assess the potential to grow fennel (Foeniculum vulgare Mill.) as an essential oil crop in the Maritime region of Canada. Three cultivars—‘Shumen’, ‘Befrena’, and ‘Sweet Fennel’—and two seeding dates—24 May and 8 June—were evaluated. Essential oil yields and composition were determined and compared to commercially available fennel essential oil from the U.S. The highest herbage yields were produced by ‘Shumen’ from the earlier seeding date. Essential oil content and yields were lowest in ‘Sweet Fennel’ and ‘Shumen’. Fenchone, ortho cymene, α-pinene, β-pinene, apiole, and α-phellandrene were the highest in ‘Berfena’. The composition of the oil was similar to the oil: the initial temperature of 75 °C, for 4 min., used to separate the components of the essential oil was stored in tinted glass vials in –5 °C for 3 d at 25 °C before oil extraction.

Materials and Methods

Experimental design. Field experiments were carried out at two Nova Scotia (Canada) locations, Truro and Canning in 2001 and 2002. The experiments were 2 × 3 factorial designs. The fields for each experiment were blocked into four areas. The two factors were seeding date (24 May and 8 June) and cultivar (‘Shumen’, ‘Berfena’, and ‘Sweet Fennel’). Plant material. ‘Berfena’ and ‘Sweet Fennel’ seeds were purchased from Richters Seeds in Canada and ‘Shumen’ seeds were acquired from the Research Institute for Roses, Aromatic and Medicinal Plants in Kazanluk, Bulgaria. Before seeding fields were amended with N at 170 kg ha⁻¹ and K at 65 kg ha⁻¹ and disked and harrowed, based on the soil tests no amendment of phosphorus was needed. Plots were 2 × 3 m with four rows of fennel in each plot, 60 cm apart. Fennel was direct seeded into the field at rates of 15 kg ha⁻¹ on 24 May and 8 June. Plants were harvested during flowering, on the same day for each location, and dried in forced air dryers for 3 d at 25 °C before oil extraction.

Essential oil extraction. Steam distillation was used to extract the essential oil using a modified Clevenger collector apparatus (Guenther, 1948) from Quickfit glassware, England. Sample size was 200 g of dried plant material. Distillation time was 120 min. After extraction oil was stored in tinted glass vials in –5 °C freezers until compositional analysis.

Essential oil analysis. For the analysis 50 µL of oil was diluted in 0.5 mL HPLC-grade hexane for injection into the gas chromatography mass spectrometer (GC)(PerkinElmerTurboMass mass spectrometer). The GC column was a Supelco MDN-55 fused silica capillary column, 30 m x 0.25 mm ID and a film thickness of 0.5 µm. The following GC temperature program was used to separate the components of the essential oil: the initial temperature of 75 °C, for 4 min., followed by 4 °C min⁻¹ increase to 199 °C with a total run time of 35 min. The injection volume was 1.0 µL and the injection temperature was 240 °C. Helium, the carrier gas, flowed at 1.0 mL min⁻¹. Both flame ionization detection (FID) and mass spectrum (MS) analyses were performed. Component concentration was determined based on the peak area from FID detection. Commercial grade standards (Aldrich, Canada) were used to identify the components in the essential oil. In addition, steam distilled commercial fennel seed essential oil grown in the United States was purchased from ATL Canada for compositional comparison.

Statistical analysis. Statistical analysis software, SAS version 8.0 (SAS Institute, 2000) was used to evaluate the significance of the difference between the two-way interaction of cultivar by seeding date, and the two main effects of cultivar and seeding date. Each year

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Fennel is an essential oil producing aromatic plant that belongs to the Apiaceae family. Oil with no more than 10% methyl chavicol or 7.5% fenchone would be acceptable (Bilia et al., 2002). The essential oil quality and productivity of fennel and other essential oil crops are depended on many factors such as climate, cultivar, seeding date, harvest date, weed pressure, plant disease, and management practices (Clark and Menary, 1979; Fahlen et al., 1997; Frank et al., 1987; Gill and Randhawa, 1996; Kothari et al., 1989; Kothari and Singh 1994; Lenardis et al., 2000; Marotti et al., 1996; Zheljazkov and Zhalnov, 1995). Fennel is grown as an essential oil producing crop in many areas of the world including the United States, Europe, and Asia. While fennel is commonly grown in the Maritime region of Canada as a culinary crop, there has been no evaluation of the effect of the regional climate on the essential oil productivity and quality.

‘Berfena’ and ‘Shumen’ were developed in Germany and in Bulgaria respectively, as early maturing varieties for essential oil production (Reichardt and Pank, 1993; Zheljazkov et al., 1996). ‘Sweet Fennel’ is commonly grown in North America (Charles et al., 1993). The above three cultivars were chosen for this study based on having been developed for essential oil production and their productivity in similar climates to Nova Scotia.

Cultivars of fennel were evaluated as potential new cash crops for essential oil production in Nova Scotia. Most horticultural crops in Atlantic Canada are grown in Nova Scotia in the area around Canning (plant hardiness zone 6) and some in the area around Truro (plant hardiness zone 5). Furthermore, growers in the region are looking for new cash crops. Therefore, to make this study more representative, these two locations were chosen to conduct the experiments.
and location was analyzed separately due to the differences between locations and years. Tukey’s studentized range test was used to compare the mean values of the treatments when significant differences were shown through the analysis of variance. Mean values were considered significantly different when \( P < 0.05 \). Transformations were performed as was necessary to meet ANOVA model assumption of normal distribution of residuals. Means presented are original raw data.

**Results**

Herbage yields ranged from 275 to 16,016 kg·ha\(^{-1}\) (fresh) and from 60 to 3,600 kg·ha\(^{-1}\) (dry) (Table 1). 'Shumen' was the fennel cultivar with the highest yields on a fresh and dry weight basis compared to 'Berfena' and 'Sweet Fennel'. Overall, the highest yields were from the first seeding date.

Essential oil content from dried herbage ranged from 0.31% to 2.17% and essential oil yields ranged from 0.05 to 1.96 L·ha\(^{-1}\) (Table 2). The highest essential oil content and yield was in fennel planted on the first seeding date. Overall 'Sweet Fennel' had the lowest essential oil content and yields compared to 'Shumen' and 'Berfena'. However, in 2002 'Sweet Fennel' from the second seeding date in Truro had more than double the essential oil content and yields then the other treatment combinations.

Anethole was the main component in the fennel essential oil with concentrations ranging from 47% to 80.2% (Tables 3–6). Generally, anethole concentration decreased with a delay in seeding date. In fennel grown in Truro in 2001 'Berfena' had lower anethole concentration than 'Sweet Fennel' and 'Shumen' (Table 4).

Fenchone, ortho cymene, \( \alpha \)-phellandrene, \( \alpha \)-pinene and \( \beta \)-pinene were greatest in 'Berfena' essential oil and lowest in 'Sweet Fennel' essential oil (Tables 3–6). 'Shumen' essential oil had the greatest concentration of methyl chavicol. Apiole and \( \beta \)-phellandrene were greatest in 'Sweet Fennel' oil. 'Berfena' essential oil contained low \( \gamma \)-terpine levels compared to 'Shumen' and 'Sweet Fennel' essential oil. Fenchyl acetate was highest in 'Sweet Fennel' oil and lowest in 'Berfena' oil. \( \beta \)-Pinene and \( \alpha \)-pinene were greatest in the first seeding date, conversely, the concentration of \( \alpha \)-phellandrene was greatest in the second seeding date.

Anethole was the main component of essential oil extracted from 'Sweet Fennel' grown in the U.S. consisting of 77% of the oil (Table 7). Fenchone (9.83%), methyl chavicol (4.46%), limonene (3.34%), and \( \alpha \)-pinene (2.27%) were the remaining main components. Those components comprised of 96.96% of the essential oil with the remaining 3% of the oil being made up of numerous components in trace amounts (<1%).

**Discussion**

Herbage yields ranged from 275 to 16,016 kg·ha\(^{-1}\) (fresh) and from 60 to 3,600 kg·ha\(^{-1}\) (dry) depending on year, location, seeding date and cultivar. These yields are slightly lower than have been reported by other authors. Butain and Chung (1994) reported herbage dry weights between 4.16 and 7.79 t·ha\(^{-1}\). In this study, the highest yields were produced by 'Shumen' (3,991 to 16,016 kg·ha\(^{-1}\) (fresh) and 964 to 3,600 kg·ha\(^{-1}\) (dry) and the first seeding date. 'Berfena' and 'Sweet Fennel' performed better in the earlier seeding date.

The three cultivars of fennel did not reach seed formation in either Truro or Canning during both 2001 and 2002. Similar problems have been reported when growing fennel in Alberta, Canada (Embong et al., 1977). For seed formation in Nova Scotia fennel would need to be seeded earlier than the earliest date that was tested, 24 May. Furthermore, the results show that an earlier seeding date produced greater herbage yields. 'Shumen' and 'Berfena' performed well with slightly lower dry yields than have been reported.

Essential oil content from dried herbage in our experiments ranged from 0.31% to 2.17%. With the exception of Truro in 2002 'Sweet Fennel' had low essential oil content. The exceptionally high essential oil content from 'Sweet Fennel' from Truro (2002) was not high enough to compensate for the very low herbage yields that were produced in that location and year. There was greater essential oil content extracted from 'Berfena' and 'Shumen' than from 'Sweet Fennel'. The oil content from 'Shumen' and 'Berfena' is similar to the wide range of composition that was found in tested commercial fennel and reported in previous research studies. Although the dynamic of essential oil content during the vegetative period was not measured, essential oil content in fennel increases as the plant matures (Gupta

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*Table 1. Herbage yields of fennel depending on location, seeding date, and cultivar.*

| Seeding date | Cultivar | 2001 | 2002 |
|--------------|----------|------|------|
| Canning      | Truro    | Canning | Truro |
| Fresh yield  | Dry yield| Fresh yield | Dry yield|
| (kg·ha\(^{-1}\)) | (kg·ha\(^{-1}\)) | (kg·ha\(^{-1}\)) | (kg·ha\(^{-1}\)) |
| 24 May       |          |       |      |
| Berfena      | 11783 a  | 2975 ab | 2679 b | 588 b |
| Shumen       | 10775    | 3600 a | 7667 a | 1933 a |
| Sweet Fennel | 5325 ab  | 1450 b | 1246 b | 396 bc |
| 8 June       |          |       |      |
| Berfena      | 817 c    | 183 ab | 612 b  | 91  d |
| Shumen       | 5056 b   | 662 a  | 5904 a | 1200 c |
| Sweet Fennel | 446 c    | 117 b  | 458 b  | 60  e |

| P value       | Date     | Cultivar | Date x cultivar |
|---------------|----------|----------|-----------------|
| Date          | <0.0001  | <0.0001  | NS              |
| Cultivar      | <0.0001  | 0.0071   | <0.0001         |
| Date x cultivar| <0.0001| <0.0001 | NS |

*Means within columns followed by different letters are significantly different at \( P < 0.05 \).*

*Table 2. Essential oil yields of fennel as affected by seeding date, and cultivar.*

| Seeding date | Cultivar | 2001 | 2002 |
|--------------|----------|------|------|
| Canning      | Truro    | Canning | Truro |
| Oil (%)      | Yield (kg·ha\(^{-1}\)) | Oil (%) | Yield (kg·ha\(^{-1}\)) |
| 24 May       |          |       |      |
| Berfena      | 0.74 b  | 1.36 a | 0.78 a | 0.45 b |
| Shumen       | 0.53 b  | 1.80 a | 0.50 abc | 0.96 a |
| Sweet Fennel | 0.47 b  | 0.65 b | 0.31 c  | 0.13cd |
| 8 June       |          |       |      |
| Berfena      | 1.05 a  | 0.16 b | 0.56 abc | 0.18 cd |
| Shumen       | 0.82 a  | 0.47 b | 0.63 ab  | 0.31 bc |
| Sweet Fennel | 0.58 a  | 0.07 b | 0.37 bc  | 0.07 d |

| P value       | Date     | Cultivar | Date x cultivar |
|---------------|----------|----------|-----------------|
| Date          | 0.0033   | <0.0001  | NS              |
| Cultivar      | 0.019    | 0.0009   | <0.0001         |
| Date x cultivar| 0.0153| <0.0001 | 0.0174 |

*Means within columns followed by different letters are significantly different at \( P < 0.05 \).*
Table 3. Essential oil composition of fennel grown in Canning, Nova Scotia, in 2001, depending on cultivar (C) and seeding date (D).

| Seeding | Berfena | Shumen | Sweet Fennel | P < |
|---------|---------|--------|--------------|-----|
| date    | 24 May  | 8 June | 24 May | 8 June | D | C | D × C |
| Anethole| 54.9    | 52.6   | 47.1   | 55.5   | NS | NS | NS |
| Methyl chavicol | 1.6b | 1.7b | 2.0a | 4.4a | 1.8b | 1.7b | NS | 0.0123 NS |
| Fenchone | 7.9a | 4.7a | 2.5b | 1.7b | 0.4b | 0.3b | 0.0159 <0.0001 NS |
| g-Terpinene | 1.6b | 2.8b | 24.7b | 22.2b | 35.5a | 28.2a | NS | 0.0009 NS |
| α-Pinene | 11.6a | 9.7a | 8.7a | 4.0a | 0.3b | 0.1b | NS | <0.0001 NS |
| Limonene | 2.0a | 2.1a | 0b | 0b | 0b | 0b | NS | <0.0001 NS |
| Ortho cymene | 3.6a | 2.9a | 1.1b | 1.1b | 0c | 0c | NS | <0.0001 NS |
| Fenchyl acetate | 0.3c | 0.2c | 2.9b | 1.7b | 7.9a | 6.7a | NS | <0.0001 NS |
| β-Pinene | 1.8a | 1.7a | 1.1b | 0.7b | 0.4c | 0.1c | <0.0001 NS |
| α-Phellandrene | 12.0b | 18.7a | 5.3c | 6.3c | 0d | 0d | 0.0030 <0.0001 0.0242 |

Means within rows followed by different letters are significantly different at P < 0.05.

Table 4. Essential oil composition of fennel grown in Truro, Nova Scotia, in 2001, depending on cultivar (C) and seeding date (D).

| Seeding | Berfena | Shumen | Sweet Fennel | P < |
|---------|---------|--------|--------------|-----|
| date    | 24 May  | 8 June | 24 May | 8 June | D | C | D × C |
| Anethole| 63.4b  | 57.0b  | 72.1ab | 58.8ab | 75.7a | 67.1a | 0.0064 0.0150 NS |
| Methyl chavicol | 0.2b | 2.1b | 3.7a | 2.7a | 2.3b | 2.0b | NS | 0.0025 NS |
| Fenchone | 8.2a | 6.5a | 1.3a | 0.8a | 0b | 0.2b | NS | 0.0025 NS |
| g-Terpinene | 0.8b | 2.0b | 11.0a | 19.3a | 4.3a | 13.0a | 0.0065 0.0007 NS |
| Limonene | 1.3b | 1.9a | 0b | 0b | 0b | 0b | NS | <0.0001 NS |
| Ortho cymene | 4.0a | 5.0a | 2.0b | 2.5b | 0c | 0c | <0.0001 NS |
| Fenchyl acetate | 0.2c | 0.2c | 2.5bc | 2.0b | 8.3a | 4.1b | 0.0062 <0.0001 0.0002 |
| β-Pinene | 1.0a | 1.3a | 0.3b | 0.5b | 0c | 0c | <0.0001 NS |
| α-Phellandrene | 5.8b | 12.5a | 1.7c | 4.0bc | 0d | 0d | 0.0056 <0.0001 0.0024 |

Means within rows followed by different letters are significantly different at P < 0.05.

Table 5. Essential oil composition of fennel grown in Canning, Nova Scotia, in 2002, depending on cultivar (C) and seeding date (D).

| Seeding | Berfena | Shumen | Sweet Fennel | P < |
|---------|---------|--------|--------------|-----|
| date    | 24 May  | 8 June | 24 May | 8 June | D | C | D × C |
| Anethole| 58.3    | 60.3   | 59.0    | 65.9    | 60.8 | 68.4 | 0.0189 NS | NS |
| Methyl chavicol | 2.0b | 2.2b | 3.1a | 2.7a | 2.1b | 2.1b | NS | 0.0002 NS |
| Fenchone | 3.5a | 3.2a | 1.2b | 1.4b | 0.2c | 0.1c | NS | <0.0001 NS |
| g-Terpinene | 2.0b | 1.1b | 18.3a | 16.6a | 25.5a | 15.1a | NS | <0.0001 NS |
| Limonene | 11.7a | 3.6b | 4.8b | 3.2b | 0.3bc | 0.1c | <0.0001 <0.0001 0.0001 |
| Ortho cymene | 1.7a | 1.0a | 0b | 0b | 0 | 0 | NS | <0.0001 NS |
| β-Phellandrene | 1.6a | 1.0a | 0.5b | 0.4b | 0c | 0c | NS | <0.0001 NS |
| Fenchyl acetate | 0.2b | 0.4b | 0.7b | 0.4b | 1.7a | 0.2a | NS | <0.0001 NS |
| Fenchone | 0.2d | 0.2d | 1.8b | 1.1c | 4.4a | 5.1a | NS | <0.0001 0.0187 |
| Apiole | 0b    | 0.1b  | 0b    | 0b    | 1.1a | 1.4a | NS | 0.0008 NS |
| β-Pinene | 1.5a | 1.0a | 0.8b | 0.7b | 0.8b | 0.4b | 0.0003 <0.0001 NS |
| α-Phellandrene | 14.9a | 15.7a | 7.8b | 6.9b | 0.0c | 0c | NS | <0.0001 NS |

Means within rows followed by different letters are significantly different at P < 0.05.

Table 6. Essential oil composition of fennel grown in Truro, Nova Scotia, in 2002, depending on cultivar (C) and seeding date (D).

| Seeding | Berfena | Shumen | Sweet Fennel | P < |
|---------|---------|--------|--------------|-----|
| date    | 24 May  | 8 June | 24 May | 8 June | D | C | D × C |
| Anethole| 58.9    | 71.5   | 60.2    | 66.6    | 57.8 | 80.2 | 0.0027 NS | NS |
| Methyl chavicol | 2.3b | 2.4b | 2.8a | 2.6a | 2.3b | 2.0b | NS | 0.0128 NS |
| Fenchone | 5.8a | 4.3a | 0.9b | 0.9b | 0.6b | 0.6b | NS | <0.0001 NS |
| g-Terpinene | 1.7   | 1.6   | 6.3    | 5.8    | 1.3 | 0.8 | NS | NS NS |
| Limonene | 1.5b | 1.1b | 9.8a | 9.2a | 9.5a | 9.4a | NS | 0.0053 NS |
| Ortho cymene | 1.1a | 1.0a | 0.6b | 0.7b | 0c | 0c | NS | <0.0001 NS |
| β-Phellandrene | 0.2c | 0.2c | 0.7b | 0.5b | 2.0a | 1.6a | 0.0162 0.0010 NS |
| Fenchyl acetate | 0.1c | 0.2c | 2.1b | 1.6b | 3.4a | 2.7a | NS | <0.0001 NS |
| Apiole | 0b    | 0b    | 0.1b | 0b    | 0b | 0b | NS | <0.0001 NS |
| β-Pinene | 1.2a | 0.8a | 0.8b | 0.7b | 0.3b | 0c | 0.0132 0.0001 NS |
| α-Phellandrene | 12.5a | 12.5a | 7.0b | 6.9b | 0.5c | 0c | NS | <0.0001 NS |

Means within rows followed by different letters are significantly different at P < 0.05.
In contrast, bitter fennel has a lower anethole concentration, 61% to 70% (Simandi et al., 1999). The fennel grown in Nova Scotia ‘Sweet Fennel’ and ‘Shumen’ contained below 5% fenchone, but ‘Berfena’ contained up to 7.9% fenchone. Oil extracted from ‘Sweet Fennel’ contained the lowest amount of fenchone with only trace amounts detected. The essential oil from fennel grown in Nova Scotia further meet the requirements stated by Bilia et al. (2002) that there should not be >10% methyl chavicol or 7.5% fenchone in the fennel essential oil.

Similar to the oil content reported here, anethole was the main component in the commercial oil extracted from the fennel seeds grown in the U.S. As the commercial oil was extracted from seeds and the essential oils from Nova Scotia were from herbage, the differences in anethole levels could be attributed to the plant maturity stage at harvest. The anethole content also varies based on botanical part. Venskonutis et al. (1996) reported 50.1% anethole in fruit and 73.6% in stems of fennel grown in Lithuania. Marotti et al. (1994) reported that as the fennel seeds matured the content of anethole increased and the limonene content decreased.

Although somewhat low the anethole content of the fennel from Nova Scotia shows promise with the essential oil from the earlier seeding date containing greater anethole concentration. Fenchone (9.83%), methyl chavicol (4.46%), limonene (3.34%), and α-pinene (2.27%) were the remaining main components. Those components comprised of 96.96% of the essential oil with the remaining 3% of the oil being made up of numerous components in trace amounts (<1%).

### Conclusions

There is good potential for ‘Berfena’, ‘Shumen’, and ‘Sweet Fennel’ to be grown as an essential oil crop in the Maritime region of Canada. There was typical herbage productivity and oil composition and with earlier seeding dates, fennel in the region could mature to seeds, which would have greater oil yields. The greatest yields and tallest plants were produced by ‘Shumen’ and the earlier seeding date. Furthermore, the essential oil content and yields were lowest in ‘Sweet Fennel’ and the greatest essential oil yields were produced by ‘Shumen’.

The main component in essential oil was anethole (47% to 80.2%). Other major components in the essential oil were methyl chavicol, fenchone, α-pinene, g-turpinol, and α-pinene. Minor components of the oil were ortho camphene, β-phenylated, fenchyl acetate, α-pinene, and anisole. The composition of each cultivar of fennel produced was unique. The composition of the oil was similar to the commercially purchased oil and met industry requirements of oil composition.

Further productivity and increased oil quality may be improved with earlier seeding to permit seed maturation. The high anethole concentration in the first seeding date of ‘Shumen’ and ‘Sweet Fennel’ essential oil is an indicator of the potential for high fennel essential oil quality from Nova Scotia. As shown there is potential to grow fennel as an essential oil crop in this region.

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