Seed oil and fatty acid composition in Capsicum spp.

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ABSTRACT

The oil content and fatty acid composition of seed of 233 genebank accessions (total) of nine Capsicum species, and a single accession of Tubocapsicum anomalum, were determined. The physicochemical characteristics of oil extracted from seed of Capsicum annuum and Capsicum baccatum were also examined. Significant differences among mean values for seed oil content were detected among the cultivated Capsicum species. Oil content in seed of C. annuum var. annuum was significantly greater than that in seed of other cultivated species. Capsicum pubescens had the lowest average seed oil content. Among the non-cultivated taxa examined, seed of Capsicum galapagoense had the lowest oil content and T. anomalum the highest. Averages across the 5 cultivated taxa for the 4 principal fatty acids were 12.9%, 3.4%, 6.7% and 76.0% for C16:0 (palmitic), C18:0 (stearic), C18:1 (oleic) and C18:2 (linoleic), respectively. Linoleic acid was the principal fatty acid in all samples, with a high value of 81% in Capsicum chienense. Capsicum frutescens had the lowest percentage of total unsaturated fatty acids and T. anomalum the highest. In general, the oil content and fatty acid composition of seed of the wild taxa were similar to those of the cultivated species.

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1. Introduction

The genus Capsicum contains 20+ species of annual and perennial herbs or shrubs that are native to Central and South America (Walsh and Hoot, 2001). It is generally agreed that five species in this genus are “cultivated” and that these include C. annuum L., Capsicum baccatum L., Capsicum chinense Jacq., Capsicum frutescens L. and C. pubescens Ruiz & Pav. (DeWitt and Bosland, 1997). Among these, C. annuum – the common bell pepper – accounts for most commercial production worldwide. However, numerous other forms of this species are also grown on a commercial scale. These would include: jalapeno, pimento, paprika, anaheim and poblano, among others. World production of bell and chile peppers is substantial and exceeded 26 × 106 MT in 2007. The U.S. imported 5 × 105 MT of dried jalapeno and anaheim peppers in 2007. Annual production data on other forms of Capsicum annuum and on other species of Capsicum such as C. frutescens (tobasco), C. chinense (habanero), C. baccatum (aji) or C. pubescens (rocoto) are not readily available, although each of these are of local, regional or – in some instances – of global importance. Grown principally for their fruit (fresh or dried), the seed is generally considered a by-product. In view of the current interest in the development of alternative sources of oil for use as fuel and other commercial applications, and the utilization of plant waste products that otherwise would be discarded (El-Adaway and Taha, 2001; Embaby and Mokhtar, 2011), the potential for the increased utilization of oil extracted from pepper (and other vegetable and fruit seed) has been emphasized by Yu et al. (2005).

Reports in the scientific literature on Capsicum seed oil content and fatty acid composition have generally been limited to C. annuum. Early studies of seed oil content by Ebert and Bailey (1924) and Bush (1936) reported values of 18% and 26%, respectively. Seed oil content varied from 12 to 26% in various Indian varieties (Wealth of India, 1950) and averaged about 24.4% in several Greek and Italian varieties (Tsatsaronis and Kehayoglou, 1970). Similar values were reported by Domokos et al. (1993) and

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Embey and Mokhtar (2011). Marion and Dempsey (1964) described the fatty acid composition of C. annuum seed oil as 67.0% C18:2, 14.8% C18:1, 11.3% C16:0 and 4.4% C18:0. Neither plant-to-plant variation nor geographical location influenced the seed oil content or the fatty acid profile. Somewhat similar values were reported by Perez-Galvez et al. (1999) – 77.0% C18:2, 7.3% C18:1, 11.0% C16:0, and 2.7% C18:0. In all of the previous studies, plant materials were exclusively C. annuum.

The chemical characteristics of chili seed oil were reported as similar to those of safflower (Sancho et al., 2002) or certain members of the Onagraceae family (Yu et al., 2005). The oil has been reported to have a pleasant flavor (Ebert and Bailey, 1924) that compares favorably with that of peanut oil (Reddy and Sarojini, 1987). The similarity of pepper seed oil to sunflower oil has also been noted (Embey and Mokhtar, 2011). In any case, the potential for the use of Capsicum seed oil as a salad oil or for use in cooking was recognized early (Ebert and Bailey, 1924). It has high levels of oxidative stability (Yu et al., 2005). The high linoleic acid content makes it both nutritious and useful in the manufacturing of margarine (Embey and Mokhtar, 2011) and mayonnaise (Ebert and Bailey, 1924). Oil extracted from pungent varieties contains capsaicin (Reddy and Sarojini, 1987) and is used to produce red pepper seed oil (RPSO), an important condiment in China (Li et al., 2011) and elsewhere. Pepper seed has also been proposed as a source of oil for industrial applications (Matthaus and Ozcan, 2009) and as a component in the formulation of UV protectants (Embey and Mokhtar, 2011). It has anti-inflammatory (Sancho et al., 2002) properties and contains vitamin E-active compounds (Matthaus and Ozcan, 2009).

Despite its recognized potential as a vegetable oil, data on the production of pepper for seed oil is lacking. No data are available on the cultivation of pepper specifically (or primarily) for the production of oil. Rather, pepper seed oil is typically prepared from the by-products of pepper fruit produced for other purposes (Li et al., 2011). Ebert and Bailey (1924) reported that seed of a locally grown pimento variety yielded ~132.5 L of oil per 0.9 MT (wet weight) of seed when pressed. Marion and Dempsey (1964) reported that ~32 × 10³ MT of pimento pepper fruit were harvested in the southeastern US in 1964, and that those fruit contained approximately 1320 MT (wet weight) of seed that would be expected to yield approximately 20% oil. Fruit of some pepper varieties are dried before processing, and in those instance seeds constitute ~60% of the total dry weight (Reddy and Sarojini, 1987). Supercritical CO₂ fluid extraction has been proposed as a desirable alternative to either mechanical extraction or chemical extraction methods for the preparation of pepper seed oil and has resulted in high rates of recovery (Li et al., 2011).

The present study was conducted in order to examine the range of seed oil content and the fatty acid composition in a genebank collection of Capsicum spp. in order to provide a more comprehensive picture of the diversity for seed oil content and fatty acid composition in the Capsicum genepool.

2. Materials and methods

2.1. Plant material

All seeds used in this study were obtained from the USDA/ARS Plant Germplasm Collection in Griffin, GA (Jarret et al., 1990). Prior to analysis, all seeds (stored at ~20 °C in foil pouches) were brought to room temperature for a minimum of 24 h. All analyses were conducted on intact seed. A total of 232 genebank accessions were examined. These included the cultivated species C. annuum (80), C. baccatum var. pendulum (40), C. chinense (39), C. frutescens (36) and C. pubescens (11), the semi-domesticated C. annuum var. glabriusculum (Dunal) Heiser & Pickersgill (21) and C. baccatum L. var. baccatum, and the wild species Capsicum eximium Hunz. (1), Capsicum flexuosum Sendtn. (1), Capsicum galapagense Hunz. (1), Capsicum tovarii Eshbaugh et al. (1) and Tubocapsicum anomalum (Franch. & Sav.) Makino (1).

2.2. Preparation of oil standards

Oil standards were prepared from C. annuum cv. California Wonder (American Meadows, Williston, VT) and C. baccatum cv. Aji Colorado (Seeds of Change, Rancho Dominguez, CA) essentially as described by Jarret et al. (2011). For each of these, ~1 kg of dried seed were ground to a fine powder in a coffee mill (Black & Decker model CBM205 – medium setting) and the powder transferred to a 1-L round bottom flask. To the flask was added sufficient heptane (Acorus Organics) to bring the volume of the mixture to ca. 500 mL. The flask was sealed, transferred to a rotary shaker (Thermolyne ARS 160) and the contents mixed for 24 h. The mixture was then allowed to settle for several hours and then twice vacuum filtered through Fisher Scientific P5 (Atlanta, GA) filter paper. The filtrates were concentrated by rotary evaporation, yielding light yellow oils. Yields were typically 18–20% by seed weight.

Seed oil and moisture measurements were carried out by TD-NMR essentially as described by Krygsman and Barrett (2004) and Jarret et al. (2011) on a Bruker (Madison, WI) mQ10 Minispec NMR operating at a resonance frequency of 9.95 MHz and maintained at 40 °C. For each signal acquisition, spin-echo parameters consisted of a 90° pulse of 10.44 μs and reading at 50 μs followed by a 180° pulse of 21.38 μs (pulse spacing = variable) and reading at 7 ms. A ± 2 s recycle delay between scans was used, and a total of 16 scans were collected for each sample. Bulk seed measurements were made in a 40-mm glass sample tube, and NMR signals were compared to oil and moisture calibration curves, generated by sample weight. All samples were measured in triplicate and the results were averaged. Moisture standards were prepared using seeds of known moisture content and calculating the mass of water present in different seed lots. Moisture content was pre-determined by measuring the differences in masses of seeds before and after oven drying at 130 °C for 3 h. All NMR oil analyses were conducted using separate seed samples drawn from the available inventory. Seed were drawn from the 01 (first regeneration) inventory of each accession, unless noted otherwise.

In order to identify an appropriate standard for the oil analysis, fifty randomly selected seed samples (including representative examples of all species included in this study) were analyzed for moisture and oil content against standard curves generated from oil extracted from C. annuum (“California Wonder”) and C. baccatum (“Aji Colorado”).

2.3. Isolation and analysis of fatty acids

For isolation of fatty acids, replicate fifty seed samples were ground to a fine powder in a coffee bean mill. Approximately 50 mg of ground powder was transferred into a 16 mm × 100 mm test tube, and 5.0 mL of n-heptane (Fisher Scientific) was added to extract the oil. For conversion of fatty acids to methyl esters (FAME), 500 μL of 0.5 sodium methoxide (NaOCH₃) in methanol solution was added to the test tube and mixed with the sample. The reaction was allowed to proceed for 2 h. Seven mL of distilled water was then added to separate the organic layer from the aqueous layer and residue (Luddy et al., 1968). An aliquot of the organic layer (1.5 mL) containing the methyl esters was transferred to a 2.0 mL autosampler vial for GC analysis.

FAME extracts were diluted 100-fold in hexane containing 25 μg/mL methyl nonadecanoate (C19:0) and analyzed with a ThermoQuest Finnigan DSQII GC-MS system (ThermoFisher, San Jose, CA, USA). C19:0 was used as an internal standard (ISTD). The
mass spectrometer was operated in the electron ionization mode and scanned at $m/z = 50–400$ during data acquisitions. Chromatographic separations were on a 30 m DB5\textsuperscript{®} column, 0.25 mm i.d., 0.25 \mu m film (Agilent, San Jose, CA, USA). Helium carrier gas flow was held constant at 1.5 mL min\textsuperscript{-1} and injection port temperature was 220 °C. Injection was in the splitless mode. The initial oven temperature of 60 °C was held for 1 min after injection and then increased to 250 °C at 8 °C min\textsuperscript{-1} and held for 5 min. Peak assignments and quantitation were based on analysis of serial dilutions of a commercially available FAME mixture. The FAME mixture (GLC-10) and ISTD were purchased from Matreya LLC (Pleasant Gap, PA, USA).

### 2.4. Determination of physicochemical properties

#### 2.4.1. Pour point

Pour points were measured by Method D97-96a (ASTM, 1996) to an accuracy of ±3 °C. The pour points were determined by placing a test jar with 50 mL of the sample into a cylinder submerged in a cooling medium. The sample temperature was reduced in 3 °C increments at the top of the sample until the material stopped pouring. The sample no longer poured when the material in the test jar did not flow when held in a horizontal position for 5 s. The temperature of the cooling medium was chosen based on the expected pour point of the material. Samples with pour points that ranged from (+9 to –6, to –24, and –24 to –42 °C) were placed in baths of temperatures (–18, –33, and –51 °C) respectively. The pour point was defined as the coldest temperature at which the sample still poured. All pour points were determined in duplicate and average values are reported.

#### 2.4.2. Cloud point

Cloud points were determined by ASTM Method D2500-99 (ASTM, 1999) to an accuracy of ±1 °C. The cloud points were determined by placing a test jar with 50 mL of the sample into a cylinder submerged into a cooling medium. The sample temperature was reduced in 1 °C increments until any cloudiness was observed at the bottom of the test jar. The temperature of the cooling medium was chosen based on the expected cloud point of the material. Samples with cloud points that ranged from (room temperature to 10.9 to –6, and –6 to –24, –24 to –42 °C) were placed in baths of temperatures (0, –18, –33, and –51 °C) respectively. All cloud points were determined in duplicate and average values are reported.

#### 2.4.3. Viscosity and viscosity index

Viscosity measurements were made using calibrated Cannon-Fenske viscometer tubes purchased from Cannon Instrument Co. (State College, PA). Viscosity measurements were made in a Temp-Trol (Precision Scientific, Chicago, IL) viscometer bath set at 40.0 and 100.0 °C. Viscosity and viscosity index were calculated using ASTM Methods D445-97 (ASTM, 1997) and ASTM D2270-93 (ASTM, 1993), respectively. All viscosity measurements were run in duplicate and the average values are reported.

#### 2.4.4. Oxidative stability

P-DSC (pressurized-differential scanning calorimetry) analyses were conducted with a TA Instruments (New Castle, DE) model DSC 2910 fitted with an HP 2910 model high-pressure DSC cell (maximum 7 MPa). A model 5000 personal computer-based controller was used for data acquisition and determination of oxidation onset temperature (OT). Purge gas outside the cell was low-pressure nitrogen. All scans were conducted with the cell pressurized with oxygen to 3000 ± 50 kPa (440 ± 7 psig). A spring-action purge valve was fitted to the exhaust line to keep the cell at constant pressure during heating. P-DSC analyses were conducted using hermetically sealed aluminum pans with a ~0.5-mm-diameter pinhole punched in the top cover to allow direct contact between the sample and pressurized oxygen. Samples were analyzed simultaneously with an identical empty pan. OT data reported in this work are means determined from replicate scans on three fresh samples.

In dynamic (positive gas flow) mode, the cell was pressurized then sealed off. After the cell was equilibrated at 25 °C, the inlet valve was opened wide and the outlet valve cracked slightly open to allow steady flow of oxygen through the cell. Oxygen flow rate was set manually to 100 ± 10 mL min\textsuperscript{-1} and monitored by a calibrated gas flow-meter connected downstream from the cell outlet valve. Once oxygen flow was established and pressure re-stabilized, the cell was equilibrated at 30 °C then heated with a ramp rate = 10 °C/min to a terminal temperature of 300 °C. Sample mass for dynamic mode scans was 1.50 mg.

#### 2.4.5. Acid value (AV) and free fatty acids (FFA)

A 751 GPD Titriso from Metrohm Ltd. (Herisau, Switzerland) was used for measurements. Acid values and % FFA were determined by the official AOCS Method Te 2a-64 with ethanol substituted for methanol to increase the solubility of the estolide esters during the titration (Firestone, 1994). All AVs were run in duplicate and average values are reported.

#### 2.4.6. Gardner color

Gardner color was measured on a Lovibond 3-Field Comparator from Tintometer Ltd. (Salisbury, England) using AOCS Method Td 1a-64. The Gardner color scale is from 1 to 18 with 1 containing the least amount of color and 18 with the maximum amount of color. In many cases, the Gardner color of materials can be susceptible to the interpretation of the recorder, thus the + and – notation was employed to designate samples that did not match one particular Gardner color.

#### 2.5. Statistical analysis

Correlations were identified via the calculation of Pearson’s product–moment correlation coefficient (R). An analysis of variance was performed on the data, and means were separated using Tukey’s Studentized range (HSD) Test. General statistical data were generated and analyzed using SigmaPlot 11.2 and SAS. Though not cultivated in the strictest sense, data from the analyses of C. annuum var. glabriusculum and C. baccatum var. baccatum are presented with those of the cultivated forms for comparative purposes. Seed oil content and fatty acid composition data are available at [www.ars-grin.gov](http://www.ars-grin.gov).

### 3. Results

#### 3.1. Physicochemical properties of the seed oil standards

The physicochemical characteristics of the oils from C. annuum (cv. California Wonder) and C. baccatum (cv. Aji Colorado) were generally similar (Table 1) with near identical cloud points, viscosities, viscosity indexes, and oxidative stabilities. The pour point of oil of cv. California Wonder was slightly lower than that of cv. Aji Colorado and its oil was a deeper yellow than that extracted from seed of cv. Aji Colorado. Seed oil estimates (via TD-NMR) were 31.6% and 28.2% for cultivars (cvs.) California Wonder and Aji Colorado, respectively. The oils varied in their FFA content and AVs, these being 0.71 vs. 4.74 and 1.43 vs. 9.44 for cvs. California Wonder and Aji Colorado, respectively. The fatty acid profiles of both cultivars were similar [California Wonder – C16:0 (11%), C18:0 (3.6%), C18:1 (8.9%), C18:2 (75%) vs. Aji Colorado – C16:0 (13%), C18:0 (2.4%), C18:1 (4.1%) and C18:2 (79%)].
Table 1
Physicochemical properties of seed oil from Capsicum annuum cv. California Wonder (CW) and C. baccatum cv. Aji Colorado (AC).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pour point (°C)</th>
<th>Cloudpoint (°C)</th>
<th>Viscosity</th>
<th>Viscosity index</th>
<th>Gardner color</th>
<th>FFA (%)</th>
<th>AV (mg/g)</th>
<th>Stability (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>6</td>
<td>19</td>
<td>25.1</td>
<td>6.6</td>
<td>239</td>
<td>4+</td>
<td>0.71</td>
<td>14301</td>
</tr>
<tr>
<td>AC</td>
<td>11</td>
<td>17</td>
<td>25.6</td>
<td>6.7</td>
<td>239</td>
<td>4+</td>
<td>4.74</td>
<td>94415</td>
</tr>
</tbody>
</table>

a FFA = free fatty acid.
b AV = acid value.

Table 2
Mean ± standard deviation (S.D.), maximum (Max), minimum (Min) and range in percent oil content and 100 seed weight in intact seed of five species of Capsicum. Percent oil determined by TD-NMR.a

<table>
<thead>
<tr>
<th>Taxon</th>
<th>n</th>
<th>Mean±</th>
<th>S.D.</th>
<th>Max.</th>
<th>Min</th>
<th>Range</th>
<th>100 seed weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. annuum var. annuum</td>
<td>80</td>
<td>28.08a</td>
<td>±2.70</td>
<td>35.94</td>
<td>22.11</td>
<td>13.83</td>
<td>0.623a</td>
</tr>
<tr>
<td>Capsicum annuum var. glabriusculum</td>
<td>21</td>
<td>21.06c</td>
<td>3.08</td>
<td>31.73</td>
<td>16.39</td>
<td>15.34</td>
<td>0.321d</td>
</tr>
<tr>
<td>C. baccatum var. pendulum</td>
<td>28</td>
<td>24.35b</td>
<td>2.95</td>
<td>32.93</td>
<td>15.58</td>
<td>13.35</td>
<td>0.520b</td>
</tr>
<tr>
<td>C. baccatum var. baccatum</td>
<td>12</td>
<td>19.50c/d</td>
<td>1.30</td>
<td>21.53</td>
<td>17.98</td>
<td>3.55</td>
<td>0.451c</td>
</tr>
<tr>
<td>C. chinense</td>
<td>39</td>
<td>21.43c</td>
<td>3.51</td>
<td>31.48</td>
<td>16.31</td>
<td>15.17</td>
<td>0.421c</td>
</tr>
<tr>
<td>C. frutescens</td>
<td>36</td>
<td>19.73c/d</td>
<td>2.89</td>
<td>31.52</td>
<td>16.13</td>
<td>15.39</td>
<td>0.396c</td>
</tr>
<tr>
<td>C. pubescens</td>
<td>11</td>
<td>18.26c</td>
<td>2.57</td>
<td>21.44</td>
<td>14.58</td>
<td>6.86</td>
<td>0.623a</td>
</tr>
</tbody>
</table>

a Time-domain nuclear magnetic resonance.
b Means within columns followed by the same letter are not significantly different (alpha=0.05) per Tukey's Studentized range (HSD) test.

3.2. Seed oil content

In no instance did the seed oil content values obtained for individual samples run against the TD-NMR standards prepared from seed of cvs. California Wonder (C. annuum) and Aji Colorado (C. baccatum) differ by more than 0.4%. Hence, all oil content data subsequently collected were derived from samples run against the standard curve prepared from C. annuum cv. California Wonder.

Seed oil content among all species/accessions analyzed ranged from 10.8% to 35.9% with a mean of 23.5% (Fig. 1). Values for seed oil content in the five individual cultivated Capsicum spp. are presented in Table 2. Significant differences were observed between the means of the seed oil contents of the various cultivated species. Seed of C. annuum var. annuum had a significantly greater seed oil content than those of the other species. C. annuum also had the highest average (28.1%), the highest maximum (35.9% – PI 438655) and the highest minimum (22.1%) seed oil content. In contrast, seed of C. pubescens had significantly lower seed oil content values when compared to the other cultivated species. Seed of C. pubescens had the lowest average (18.3%), the lowest maximum (21.4%) and the lowest minimum (14.6%) oil content. The ranges of values observed within the cultivated species were similar (average 14.9), with the exception of C. pubescens (6.9). Among the related taxa (Table 3), the lowest oil content value was observed in the seed sample of C. galapagoense (10.8%), a small-fruited species related to other members of the C. annuum group (Walsh and Hoot, 2001) and the highest in the sample of T. anomalum (25.1%). Significant differences in seed weight among cultivated species were detected (Table 2) with a correlation (seed weight × seed oil content) of R = 0.35.

In order to estimate the effect of environmental influences on seed oil content, individual inventories of seed of seven accessions of C. annuum were analyzed. The data indicate (Table 4) that the seed oil content in the different inventories of the seed of these accessions that were produced at different locations and at different times, were quite similar. The average difference between inventories across all accessions was ~2.4%, suggesting limited environmental effects on seed oil content.

3.3. Fatty acids composition

Significant differences between the means of the principal fatty acids among the cultivated species were detected (Table 5). Averages among the taxa examined for the 4 principle fatty acids were 12.9%, 3.4%, 6.7% and 76% for C16:0, C18:0, C18:1 and C18:2, respectively. Percentages of C16:0, C18:0, C18:1 and C18:2 were significantly higher in C. annuum var. glabriusculum, C. pubescens, C. frutescens and C. baccatum var. pendulum, respectively, than in the other cultivated taxa examined. The highest values observed for individual seed samples were; C16:0 – C. annuum var. glabriusculum (18.8%), C18:0 – C. frutescens (7.9%), C18:1 – C. baccatum (12.58%) and C18:2 – C. chinense (81.1%). The lowest values observed within each category were; C16:0 – C. pubescens (9.3%),

Fig. 1. Frequency histogram of oil content in seed of nine Capsicum spp. (n = 233) and Tubocapsicum anomalous (n = 1), as determined by TD-NMR.

Table 2
Percent oil content and fatty acid composition (percent of total) in intact seed of four wild species of Capsicum and Tubocapsicum anomalous.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>n</th>
<th>Oil (%)</th>
<th>C16:0</th>
<th>C18:0</th>
<th>C18:1</th>
<th>C18:2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capsicum eximium</td>
<td>1</td>
<td>21.2</td>
<td>14.0</td>
<td>2.7</td>
<td>6.5</td>
<td>75.0</td>
</tr>
<tr>
<td>Capsicum fluviusum</td>
<td>1</td>
<td>17.1</td>
<td>13.0</td>
<td>2.6</td>
<td>8.3</td>
<td>73.0</td>
</tr>
<tr>
<td>Capsicum galapagoense</td>
<td>10.8</td>
<td>14.0</td>
<td>3.3</td>
<td>8.5</td>
<td>71.0</td>
<td></td>
</tr>
<tr>
<td>Capsicum tovari</td>
<td>1</td>
<td>18.0</td>
<td>13.0</td>
<td>2.1</td>
<td>6.3</td>
<td>76.0</td>
</tr>
<tr>
<td>Tubocapsicum anomalous</td>
<td>1</td>
<td>25.1</td>
<td>9.0</td>
<td>2.2</td>
<td>6.3</td>
<td>80.0</td>
</tr>
</tbody>
</table>
Table 4
Seed oil content in various inventories of seven genebank accessions of C. annuum produced in different locations and in different years as determined by TD-NMR.*

<table>
<thead>
<tr>
<th>Accession #</th>
<th>Inventory</th>
<th>Date produced</th>
<th>Location</th>
<th>Mean oil (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>224405</td>
<td>01</td>
<td>1969</td>
<td>Unknown</td>
<td>20.87</td>
</tr>
<tr>
<td>224405</td>
<td>02</td>
<td>1996</td>
<td>Byron, GA</td>
<td>20.80</td>
</tr>
<tr>
<td>609648</td>
<td>02</td>
<td>2003</td>
<td>Griffin, GA</td>
<td>14.77</td>
</tr>
<tr>
<td>609648</td>
<td>03</td>
<td>2004</td>
<td>Byron, GA</td>
<td>15.05</td>
</tr>
<tr>
<td>532978</td>
<td>01</td>
<td>2001</td>
<td>Griffin, GA</td>
<td>27.53</td>
</tr>
<tr>
<td>532978</td>
<td>02</td>
<td>2007</td>
<td>Byron, GA</td>
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* Time-domain nuclear magnetic resonance.

C18:0 – C. annuum var. glabriusculum (2.4%), C18:1 – C. baccatum (4.0%) and C18:2 – C. frutescens (58.1%). Ranges for the values of individual fatty acids among the related species were similar, with the exception of that for linolenic acid (C18:2) in C. frutescens which was approximately twice (19.4%) that observed for any of the other cultivated species. The fatty acid profiles of the related taxa (Table 3) were similar to those of the cultivated species. However, the lowest concentration of C16:0 observed occurred in the sample of T. annuum (PI 501532 ~9%) and the lowest concentration of C18:0 in C. tovarii (2.1%).

4. Discussion

Reddy and Sarojini (1987) compared the physicochemical characteristics of pepper (C. annuum) oil with that of peanut oil. Though having identical FFA values (0.8), and near-identical saponification values (193 vs. 194), the oils of C. annuum and C. baccatum included in the present study differed to a large extent for AVs and FFAs. We attribute a portion of the differences in AVs and FFAs to differences in seed age and seed storage conditions prior to extraction. The seed of Aji Colorado were more than 2 years old and the seed of CA Wonder <1 year. However, the extent to which seed age and storage conditions affected FFAs and AVs, was not determined.

Previously published data on many of the physicochemical properties of Capsicum seed oil were not found in the scientific literature. Ebert and Bailey (1924) reported a FFA value of 9.3% in the pimento variety used in their study. Marion and Dempsey (1964) noted the attractive golden yellow color of the oil extracted from seed of pimento pepper. However, a Gardner Color Value was not determined. For comparison with the values observed in the present study, peanut oil typically has a Gardner color of ~4 (Dean et al., 2011). An AV 2.18 was reported by Bush (1936) for a pimento variety of C. annuum and an AV of 2.96 by El-Adaway and Taha (2001) for their paprika seed oil. Acid value can be used as a measure of oil quality and is positively correlated with FFA content. For example, it has been recommended that peanut oil have an AV of a maximum of 3.5–4.0. The data on physicochemical presented in Table 1 were obtained from seed oil of only a single cultivar each of two species. It is to be expected that specific values for these properties will vary within and among Capsicum species.

We observed a range in seed oil content of from 10.8% to 35.9% across all seed samples (all species) analyzed. The upper value in this range is in general agreement with (though somewhat higher than) that reported by Matthaus and Ozcan (2009) for ten varieties of pimento (C. annuum) collected in Turkey and Italy (32.6%, average 19.1%). However, the lowest value observed in the present study for C. annuum was ~22% – considerably higher than the lowest value reported by Matthaus and Ozcan (2009) (8.6%) or Krstic et al. (2001) who reported seed oil yields of 10.78% to 21.0% in two varieties of C. annuum. This difference may be attributable to any of several factors such as the efficiency of the method(s) utilized to extract the oil and/or the proper identification of the plant materials. For example, various studies refer to their use of “paprika” peppers. Although paprika generally refers to C. annuum, it is also used in a general sense to refer to pepper fruit that are utilized as a spice or for coloration and it is sometimes used to refer to more than a single species. In a similar manner, various studies refer to the experimental materials utilized as chile (or chili) peppers. These terms likewise can be used in a generic sense to refer to Capsicum spp.

The ranges in seed oil content within the cultivated species – other than C. pubescens – were similar (range = 14.8), but considerably larger than C. pubescens (range = 6.9). Since only a limited number of C. pubescens accessions were available for analysis, differences in sample size could account for the smaller range observed among the C. pubescens accessions. Seed oil content values of the related taxa were similar to those of the cultivated species. However, previously published data on species other than C. annuum were not found, and so a direct comparison with earlier reports cannot be made.

Both Marion and Dempsey (1964) and Tsatsaronis and Kehayoglou (1970) noted small (generally <1%) differences in oil yields from seed harvested from pepper (C. annuum) fruit grown at different times and in different environments. The data reported in the present study lend support to these findings and suggest that seed oil content is relatively (within limits) stable regardless of seed production location. Seed regenerations are typically performed when inventory levels are quite low. While the number of available seed in the most current inventories analyzed in this study was sufficient to permit repeated samplings without replacement, those of the older inventories were not. Hence, statistical analysis of differences between inventories of accessions was not possible. We suggest that while environmental effects/seed age had a limited

Table 5
Means* (±standard deviation) of the principal fatty acids in seed of five Capsicum species.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>n</th>
<th>C16:0</th>
<th>C18:0</th>
<th>C18:1</th>
<th>C18:2</th>
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<tr>
<td>Capsicum annuum var. annuum</td>
<td>80</td>
<td>13.38bc (1.34)</td>
<td>3.61ab (0.61)</td>
<td>6.55b (1.06)</td>
<td>76.10bc (1.45)</td>
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<tr>
<td>Capsicum annuum var. glabriusculum</td>
<td>21</td>
<td>14.43a (1.36)</td>
<td>3.25b (0.56)</td>
<td>6.09bc (1.52)</td>
<td>75.88bc (2.03)</td>
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<tr>
<td>Capsicum baccatum var. pendulum</td>
<td>28</td>
<td>13.07bc (0.92)</td>
<td>3.23bc (0.68)</td>
<td>5.42c (1.06)</td>
<td>77.93a (0.31)</td>
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<tr>
<td>Capsicum baccatum var. baccatum</td>
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<td>13.16bc (0.74)</td>
<td>2.74c (0.65)</td>
<td>6.46b (2.15)</td>
<td>77.25ab (2.40)</td>
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<tr>
<td>Capsicum chimeroe</td>
<td>39</td>
<td>12.52d (0.79)</td>
<td>3.44b (0.73)</td>
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<td>Capsicum frutescens</td>
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<td>13.85ab (1.12)</td>
<td>3.28bc (1.22)</td>
<td>7.51a (1.13)</td>
<td>73.92d (3.40)</td>
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<td>Capsicum pubescens</td>
<td>11</td>
<td>10.62a (0.93)</td>
<td>3.95a (1.04)</td>
<td>7.58a (0.94)</td>
<td>76.00bc (1.81)</td>
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* Means within columns followed by the same letter are not significantly different (alpha = 0.05) per Tukey’s Studentized range (HSD) test.
influence on seed oil content within the materials examined, further examination of the influence of environmental effects is likely warranted. The relative stability of seed oil content across time and locations would facilitate efforts to select for increased levels of seed oil.

Reddy and Sarojini (1987) noted on the similarity between the chemical characteristics of chili seed oil and that of peanut, but less so the fatty acid composition. While the percentage of stearic acid was similar in the two, the percentages of palmitic, oleic and linoleic acids were quite different being 16.4% palmitic acid, 2.15% stearic acid, 70.6% linoleic acid and 10.9% oleic acid in chili vs. 9.0% palmitic acid, 3.0% stearic acid, 58.0% linoleic acid and 30.0% oleic acid in peanut. The average fatty acid composition (all species) in the present study (C16:0 − 13.2 ± 1.38; C18:0 − 3.38 ± 0.82; C18:1 − 6.6 ± 1.33; C18:2 − 76.14 ± 2.36) was closer to that reported by Yu et al. (2005) for members of the Onagraceae (80.0–109% palmitic; 2.4–3.5% stearic; 8.7–13.1% oleic; 71.5–80.0% linoleic). The importance of linoleic acid in the human diet was discussed by Conner (1999). Deficiency leads to poor growth, skin lesions, reproductive failure and other symptoms. It also provides protection against ischemic heart disease. Published values of percent saturated fatty acid in seed of C. annuum range from 11.89% (Tsatsaronis and Kehayoglou, 1970) to 18.5% (Reddy and Sarojini, 1987). Values in the present study (all species examined) ranged from 10.8% (C. gallopogonense – Pi 639682) to 35.8% (C. annuum – Pi 4386655), Published ranges of total percent unsaturated fatty acids range from 81.5% (Reddy and Sarojini, 1987) to 87.7% (Tsatsaronis and Kehayoglou, 1970). The range observed in the present study (75.2–87.3%) is in general agreement with the published literature, though somewhat larger.

All previous reports on the fatty acid composition of Capsicum seed oil have noted the high (generally >70%) concentration of linoleic acid and the much smaller quantities of C16:0 and C18 saturated and unsaturated acids (Marion and Dempsey, 1964). Our data support these findings and extend their known ranges. Values for individual accessions and species should not be considered as absolute because, in contrast to the relative stability of seed oil content, the fatty acid composition of seed is known to be affected by climatic conditions during seed development (Xu and Kalkafi, 2003; Demir et al., 2008). Data on the fatty acid composition of seed of Capsicum spp. other than C. annuum could not be located in the scientific literature. The data presented indicate that within the genus the fatty acid composition of the species examined is generally similar.

With few exceptions, seeds of vegetable crops are typically considered a by-product of limited value. Vegetable breeding programs often emphasize a reduction in seed production (number and/or size), as opposed to selecting for enhanced seed production – as is typically the case in oil seed and grain crops. Hence, it should not be surprising that data which documents the potential for enhancing seed production in vegetable crops using conventional breeding approaches is lacking in the scientific literature. Field evaluation of hundreds of C. annuum genebank accessions examined over a period of years suggests that rapid improvement in seed yield of C. annuum may be anticipated, and significantly enhanced in the absence of any simultaneous selection for increased fruit size and/or quality attributes. However, the extent to which C. annuum seed oil could be commercialized and marketed on a larger scale than it currently is, remains to be determined.

5. Conclusions

Data on seed oil content and fatty acid composition, among and within Capsicum species (except for C. annuum), are lacking in the scientific literature. This report documents the range of seed oil content in nine species of Capsicum and a related genus as 10.8–35.9%. Significant differences in oil content and individual fatty acids were detected among the cultivated species. The seed oil content and fatty acids (% of total) in the wild species were similar to those in the cultivated Capsicum species.

Acknowledgements

We wish to recognize the expert technical assistance of Ms. Sarah Moon Griffin, (GA) for the extraction of fatty acids, Mr. Chris Taturn (Griffin, GA) for the TD-NMR analysis of the seed oil content and Sally Bellflower (Tifton, GA) for assistance with FAME analysis. We also wish to thank Mr. Jerry Davis (University of Georgia – Griffin) for assistance with the statistical analyses.

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