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EVALUATION OF NEW *LESQUERELLA* AND *PHYSARIA* (BRASSICACEAE) OILSEED GERMPLASM[1]

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The seed oil of *Lesquerella* and the closely related genus *Physaria* (Brassicaceae) is rich in hydroxy fatty acids (HFAs). HFAs and their derivatives are used to produce a variety of industrial products including lubricants, nylon-11, plastics, drying agents, protective coatings, surfactants, cosmetics, and pharmaceuticals. *Lesquerella fendleri* is being developed as a new crop for arid regions of the southwestern United States as an alternative source of HFAs. Between 1995 and 2001, 66 accessions from 28 species of *Lesquerella* were collected in the United States, 33 accessions from four species were collected in Mexico, and 41 accessions from 15 species of *Physaria* were collected from the southwestern United States. Mean seed mass ranged from 0.54 to 2.30 mg for *Lesquerella* compared to 1.70 to 5.80 mg for *Physaria*. Seed oil content ranged from a high of 32.2% in *Lesquerella* to a high of 35.4% in *Physaria*. The fatty acid profile of all species of *Physaria* and most of the lesquerolic-acid-rich species of *Lesquerella* contained from 30 to 55% lesquerolic acid, although several species contained >60%. These collections of wild germplasm provide a diverse gene pool that should enhance our breeding program in developing a domestic source of HFAs.

Key words: hydroxy fatty acids; germplasm; *Lesquerella*; *Physaria*; new crops; seed oil.

Hydroxy fatty acids (HFAs) derived from vegetable oils serve as a chemical feedstock in the production of a variety of products including industrial lubricants (such as greases, hydraulic fluids, and motor oils), nylon-11, plastics, drying agents, protective coatings, surfactants, cosmetics, and pharmaceuticals (Roetheli et al., 1991). HFAs have arisen independently in many genera in several unrelated plant families (e.g., Apocynaceae, Asteraceae, Brassicaceae, Coriariaceae, Euphorbiaceae, Fabaceae, Malpighiaceae, Papaveraceae, and others) (Badami and Patil, 1981), most likely through the divergence of a few amino acid substitutions that convert desaturases to hydroxylases (Broun et al., 1998). The only HFA currently available in sufficient quantities for commercial purposes is ricinoleic acid (12-hydroxy-octadec-cis-9-enoic acid: 18:1-OH) from castor bean oil (*Ricinus communis* L., Euphorbiaceae). Castor oil, considered a strategic material by the United States Government, is stockpiled. The United States imports roughly 45 000 metric tons of castor oil a year, mostly from Brazil, China and India, with a value of about $35 million (West, 2002). Castor can be grown in the United States but has not since 1970. The seeds contain the highly toxic protein ricin and the alkaloid ricinine, plus additional compounds that induce allergic reactions in field workers (Weiss, 2000). Moreover, the disposal of the toxic seed meal is an issue of concern. Having a safe and affordable domestic alternative to imported castor oil would be advantageous to the U.S. economy for several reasons, including: decreasing the vulnerability of the United States to foreign events and fluctuating world markets; improving the balance of trade; diversifying crop rotations; providing biodegradable substitutes for petroleum products; and increasing rural economies by stimulating new industries (Janick et al., 1996).

Species of *Lesquerella* and the closely related genus *Physaria* (Brassicaceae) have seeds that accumulate HFAs as the predominant fraction of their seed oil profile (Hayes et al., 1995; Dierig et al., 1996). Several species of *Lesquerella* have been determined to have favorable agronomic potential for new crop development as sources of HFAs for industrial purposes (Barclay et al., 1962; Gentry and Barclay, 1962; Mikolajczak et al., 1962). Along with revenue from the HFAs, co-products of seed oil production in *Lesquerella* have the potential to significantly increase the return generated from the crop, which could lead to greater utilization. For example, profitable outlets exist for the seed meal of *Lesquerella* because it has favorable nutritional qualities (i.e., it is high in protein and has a good amino acid balance with high levels of lysine) that make it desirable for livestock and poultry feed (Miller et al., 1962; Carlson et al., 1990; Roetheli et al., 1991). Gums from the seed coats of several species of *Lesquerella* are potentially as valuable as the oil, and could be used as thickening or gelling agents in edible and nonedible products, especially in the pharmaceutical industry (Holser et al., 2000).

Vegetable oils are receiving increased attention as lubricants because they are biodegradable and generally have better lubricating properties than petroleum-based products. However, vegetable oils suffer from low temperature (solidification) and oxidative stability problems (Erhan and Asadauskas, 2000; Is-

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bell et al., 2001). The seed meal of *Lesquerella* contains antioxidants derived from glucosinolates, and the oil from several species contains estolides. Both the antioxidants and the estolides can be used as inexpensive biodegradable additives that impart superior oxidative stability and pour point (the minimum temperature at which a liquid will pour) to industrial vegetable oils (Hayes et al., 1995; Isbell et al., 2001), which should increase the opportunities to expand lesquerella oil into diverse and profitable markets.

Roughly 87 species of *Lesquerella* occur in North America and about 24 species of *Physaria* occur in the western United States (Rollins, 1993). The fatty acid profiles of four *Lesquerella* species native to the eastern United States are dominated by densipolic acid (12-hydroxy-octadec-cis-9,15-enoic acid: 18:2-OH). *Lesquerella auriculata* (Engelm. & Gray) Wats., native to Oklahoma and Texas, contains auricolic acid (14-hydroxy-eicos-cis-11,17-enoic acid: 20:2-OH) as the main fatty acid in the seed oil. The western species of *Lesquerella* and two species of *Physaria* reported previous to this study have lesquerolic acid (14-hydroxy-eicos-cis-11-enoic acid: 20:1-OH) as the main fatty acid in the seed oil (Hayes et al., 1995; Dierig et al., 1996). These three fatty acids are structurally homologous to ricinoleic acid, with the exception of either an additional unit of unsaturation and/or an additional two carbon atoms at the carboxyl end. Because they are similar to ricinoleic acid they can serve as substitutes for castor oil, and because they have some chemical differences they also have novel properties that could lead to new products.

Lesquerella fendleri (Gray) Wats., native to the southwestern United States and northern Mexico, is currently being bred and commercialized by the USDA-ARS, U.S. Water Conservation Laboratory (USWCL) in collaboration with other government agencies, universities and private industries as an oilseed crop for HFAs. *Lesquerella fendleri* has the most promise for domestication in the arid parts of this region because of its superior productivity and amenability to farm management practices (Gentry and Barclay, 1962; Dierig et al., 1993). Harvesting and processing of *L. fendleri* seed can be achieved with traditional farm equipment so no new investment in machinery is needed. As a new crop, there are no indications that lesquerella suffers from any notable crop diseases or from any major insect pests. It therefore requires fewer pesticides than traditional crops such as cotton and wheat. Granted that, as with most crops, pests and diseases arise with large-scale production. Although an active breeding program for *L. fendleri* has only been in place since 1985, much has been learned about its harvesting, water, fertilizer and herbicide requirements, planting methods, salt tolerance, inheritance of male-sterility, and ovule culture (Coates, 1994; Nelson et al., 1996; Roseberg, 1996; Hunsaker et al., 1998; Dierig et al., 2001, 2003; Tomasi et al., 2002).

The most important factors that will determine the success of lesquerella as an oilseed crop are the seed yield (e.g., seed mass, and percentage oil content of the seed) and quality of the oil produced. A great deal of natural variation in these traits exists both within and between species (Hayes et al., 1995; Dierig et al., 1996). The quality of the oil is largely determined by the HFA content of the oil. Oils that occur in plants as energy reserves are mainly mixtures of triacylglycerols (TAGs), which are combinations of fatty acids (long-chain hydrocarbon carboxylic acids) esterified to the three hydroxyl groups of a glycerol molecule (Åppelqvist, 1989). Many species can be distinguished by their fatty acid profiles, which are regulated by genes controlling fatty acid and TAG biosynthesis enzymes. In a study of the TAG structure of several species of *Lesquerella*, Hayes et al. (1995) found that a majority of the species with lesquerolic acid as the predominant HFA contain two lesquerolic acids at the *sn*-1 and *sn*-3 positions, but are not able to include this HFA at the *sn*-2 position. This theoretically limits the lesquerolic content of the oil to 66%. In contrast, those species in which lesquerolic acid was detected at significant amounts in all three positions had concentrations of lesquerolic acid up to 80%.

In order to sustain improvements for our breeding program of *Lesquerella*, we need to broaden the genetic base of our breeding lines. This requires assessing the genetic diversity in wild germplasm that could provide genetic variability on a large scale (e.g., for polygenic traits such as yield), or for single to a few gene traits (e.g., some oil quality traits). More information is needed about the adaptability and potential use of this germplasm. We report on the evaluation of collections of *Lesquerella* and *Physaria* germplasm made in the United States and Mexico from 1995 to 2001 for seed mass, oil content, and fatty acid profile and discuss the significance of these collections in relation to the breeding program and commercialization effort currently underway for *Lesquerella*.

MATERIALS AND METHODS

Collections—Prior to collecting trips a database was generated from locality data in Rollins and Shaw (1973) and from accessions in several herbaria including Universidad Autónoma Agraria Antonio Narro, Mexico (ANSM), Arizona State University (ASU), Brigham Young University (BRY), University of Colorado at Boulder (COLO), Gray Herbarium (GH), Missouri Botanical Garden (MO), and University of Wyoming (RM). The database, which contains information about flowering and fruiting times in addition to locality data, was used to plan dates and routes for collection trips. Three main collection areas were explored during four years (Table 1): Alabama, Oklahoma, and Tennessee in 1995; Colorado, Utah, and Wyoming in 1996; and Mexico in 1999 and 2000. One additional exploration trip was conducted in 2001 in Arizona, Colorado, and New Mexico. Two trips were made to each collection site. An initial trip was made to locate the plants when they were flowering so that they could be seen and mapped more readily. A follow-up trip to each site was made at a later date to collect mature fruits. Each collection site was recorded using a Global Positioning System (GPS) for latitude, longitude, and elevation, along with traditional geographical and ecological information for specimen label data. At least one voucher specimen was made for each collection and was used for species identification and documentation. One voucher specimens for each accession was deposited at ASU and duplicates, when available, were distributed. Duplicates were collected for all populations obtained in Mexico and were sent to ANSM and to Universidad Nacional Autónoma de México (MEXU). Collections from Mexico and the Navajo Nation were acquired under the auspices of the Instituto Nacional de Ecologia SEMARNAP permit number DOO 750-1121 and Navajo Fish and Wildlife permit number 990607-049, respectively. Locality information for the collections is available from the authors on request. Seed from three species of *Lesquerella* was not collected by us but was obtained from other sources: *L. katheryn* Rollins from Reed Rollins, Gray Herbarium, Harvard University, Cambridge, Massachusetts; *L. pallida* (Torr. & Gray) Wats. from San Antonio Botanical Gardens, Texas; and *L. tuplashensis* Rollins, Beck & Caplow from USDA-ARS, Western Regional Plant Introduction Station, Pullman, Washington. Seed was cleaned from the fruits and other debris by hand and stored in manilla envelopes at 18°C and 10–20% relative humidity until analyzed.

Collections that did not yield sufficient amounts of seed for oil and fatty acid analysis were increased at the USWCL, Phoenix, Arizona following the methods described by Dierig et al. (1996). Additionally, several accessions were grown out at the USWCL for comparison of the environmental plasticity of the fatty acid profiles within the same accessions of several species. All

TABLE 1. Species of *Lesquerella* and *Physaria* collected in the United States between 1995 to 2001, and Mexico between 1999 to 2001 for analysis at the USWCL. Numbers in parentheses reflect the number of populations collected. An asterisk (*) denotes species for which seed mass, oil characteristics, and fatty acid have not previously been reported.

United States	
Alabama	*L. lyrata* (2)
Arizona	*L. fendleri* (2), *L. intermedia* (1), *L. rectipes* (1)
Colorado	*L. calcicola** (1), *L. fendleri* (1), *L. ludoviciana* (4), *L. parviflora** (1), *P. acutifolia** (4), *P. bellii** (2), *P. floribunda* (5), *P. obcordata** (1), *P. vitulifera** (4)
New Mexico	*L. navajoensis** (1), *L. valida** (1)
Oklahoma	*L. angustifolia* (3), *L. auriculata* (3), *L. gordonii* (10), *L. gracilis* (3), *L. ovalifolia* (10)
Tennessee	*L. densipila* (1), *L. lescurii* (1)
Texas	*L. pallida** (1)
Utah	*L. hemiphysaria** (1), *L. hitchcockii** (1), *L. intermedia* (3), *L. ludoviciana* (1), *L. montana** (1), *L. multiceps** (1), *L. occidentalis** (1), *P. acutifolia** (5), *P. chambersii** (7), *P. lepidota** (2), *P. newberryi* (1), *P. stylosa** (1)
Washington	*L. touplashensis** (1)
Wyoming	*L. condensata** (1), *L. garrettii** (1), *L. ludoviciana* (3), *P. brassicoides** (2), *P. dornii** (1), *P. eburniflora** (2), *P. saximontana** (1), *P. vitulifera** (1)
Mexico	
Coahuila	*L. argyraea* (4), *L. fendleri* (13), *L. mexicana** (1)
Durango	*L. fendleri* (2)
Nuevo Leon	*L. fendleri* (1), *L. inflata* (1)
San Luis Potosi	*L. argyraea* (1)
Zacatecas	*L. argyraea* (1), *L. fendleri* (8)

collections that were increased at the USWCL are denoted in Tables 2–4 with an ''i'' after the accession number to indicate that the seed was increased.

Seed mass, fatty acid, and oil analysis—Because of their individual small size and highly variable mass, 1000, 500, or 200 mature seeds (depending on how many seeds were available) from each accession were weighed in bulk on a Mettler AE 1000 analytical balance (Mettler Toledo, Columbus, Ohio, USA) to 0.01 mg. The bulk mass was then divided by the number of seeds weighed in order to express the bulk mass as individual seed mass.

Total seed oil content was measured using a calibrated PC120 or mq20 Pulsed NMR analyzer (Bruker Biospin Corp., Billerica, Massachusetts, USA), and was expressed as percent dry mass, as calculated by the instrument. In order to obtain accurate measurements of total seed oil content a minimum of two grams of seed was used. For the several accessions that did not have a sufficient quantity of seed for analysis, ''na'' (data not available) was entered in the column for percent oil in Tables 2–4.

Fatty acid analysis was conducted on an HP 5890 gas chromatograph (Agilent Technologies, Willmington, Delaware, USA), with a 25 m $\times$ 0.25 mm i.d. polar column according to the method of Dierig et al. (1996). From each sample, 1–3 μL was injected using an auto-sampler. The injection port temperature was 245°C, the oven temperature was 175°C, and the detector was 275°C. The carrier gas used was helium at a pressure of 641 kPa. For each analysis, 20–90 mg of seed samples were used. Peaks were identified using Equivalent Chain Lengths and by comparison with known standards. A mean value and SD was computed for all accessions within a species, for which at least two accessions were collected.

RESULTS AND DISCUSSION

From 1995 to 2001, seed from 66 accessions from 28 species of *Lesquerella* were collected in the United States, and 33 accessions from four species were collected in Mexico (Table 1). Between 1996 and 2001, 41 accessions from 15 species of *Physaria* were collected from the southwestern United States.

Seed mass—Striking differences existed between the seed mass of species from our collections (Tables 2–4). The mass of a single seed accession evaluated varied from 0.35 mg in *L. fendleri* (accession No. 4062i), to 0.50 mg in *L. auriculata*, *L. argyraea* (Gray) Wats., and *L. gracilis* (Hook.) Wats. (accession Nos. 3009, 4014i, and 2928i, respectively), to 5.83 and 5.74 mg in *P. lepidota* Rollins and *P. obcordata* Rollins, respectively (accession Nos. 3018, and No. 3096). Interestingly, the five species (*L. auriculata*, *L. argyraea*, *L. fendleri*, *L. gordonii*, and *L. gracilis*) with the lowest seed mass are annuals (although *L. fendleri* grows as a perennial as well) and the two highest are perennials. All of the densipolic-acid-rich species are annuals, whereas the lesquerolic-acid-rich species of *Lesquerella* are annuals, biennials, or perennials. All members of the genus *Physaria* are perennial. In a study of Fabaceae, Levin (1974) found that seed mass increased with increasing woodiness. While no species of *Physaria* or perennial species of *Lesquerella* would be considered woody, the perennials are much more lignified than the annuals. Seed mass means were calculated for the densipolic-acid-rich species of *Lesqerella*, and for *Physaria*. The mean seed masses were 0.76, 1.18 and 2.84 mg for the densipolic-acid-rich and for lesquerolic-acid-rich species of *Lesquerella*, and for *Physaria* respectively. These results support the expectation of increasing seed size from annuals to perennials.

The range of seed mass varied from 0.50 to 1.15 mg (accession Nos. 3009 and 2903i, respectively) in the densipolic-acid-rich species of *Lesquerella* (Table 3) and from 0.30 to 2.40 (accession Nos. 3010 and 3103, respectively) mg in the lesquerolic-acid-rich species of *Lesquerella* (Table 2). *Physaria* seed mass ranged from to 1.34 to 5.83 mg (accession Nos. 3154 and 3018, respectively) (Table 4). Little variability was observed within species for seed mass of the auricolic- and densipolic-acid-rich species, which may be due to the low number of accessions collected. The lesquerolic-acid-rich species of *Lesquerella* had a great deal of variation in seed mass within species. Of particular interest to our group was the variation within *L. fendleri*, where the range varied from 0.35 to 0.75 mg (accession Nos. 4062i and 4056i, respectively) with a mean of 0.60 mg. Even though the range of values observed here falls within the values for *L. fendleri* reported by Dierig et al. (1996) and the mean is identical to the germplasm in our breeding line (Dierig et al., 1993; Thompson et al., 1989),

TABLE 2. Seed mass, percent oil content, and fatty acid composition of lesquerolic-acid-rich *Lesquerella* species. An asterisk (*) denotes accessions collected in Mexico, ''na'' indicates data not available, ''i'' indicates seed was increased at USWCL.

Species	Accession no.	Seed mass (mg)	Oil (%)	Fatty acid composition (%)[a]										
				16:0	16:1	18:0	18:1	18:2	18:3	20:1	18:1-OH	18:2-OH	20:1-OH	20:2-OH
L. angustifolia	2925	na	20.1	1.9	0.0	1.4	15.6	10.4	2.6	0.0	0.0	0.0	61.4	0.0
	2925i	2.30	11.8	1.6	0.7	2.2	16.8	8.5	14.3	1.0	0.0	0.0	51.4	3.0
	2927	2.20	17.6	1.8	0.0	1.4	15.7	9.7	3.6	0.0	0.0	0.0	61.7	0.0
	2927i	1.68	11.0	2.2	1.2	0.0	15.3	11.2	3.3	0.0	2.7	0.0	64.2	0.0
	2933	2.35	23.9	1.7	0.0	1.5	15.2	9.2	2.9	0.0	0.0	0.0	62.4	0.0
	Mean	2.13	15.6	1.8	0.4	1.3	15.7	9.8	5.3	0.2	0.5	0.0	60.2	0.6
	SD	0.31	5.48	0.24	0.54	0.79	0.64	1.05	5.00	0.45	1.21	0.00	5.07	1.33
L. argyraea	3196*	1.10	20.2	1.3	0.0	2.6	19.6	9.1	8.5	0.8	0.0	0.0	56.8	1.2
	3342i*	1.30	18.4	1.4	0.8	2.0	15.3	8.5	11.6	0.6	0.0	0.0	57.8	1.9
	4004i*	0.51	19.3	1.7	0.0	2.4	15.2	8.2	13.0	0.8	0.0	0.0	55.5	3.2
	4014i*	0.50	20.3	1.7	0.6	2.8	16.6	8.7	12.8	0.9	0.0	0.0	53.2	2.9
	4017i*	0.60	11.7	1.7	0.0	2.0	18.5	7.3	20.3	0.0	0.0	0.0	46.7	2.7
	4030*	1.05	17.2	0.9	2.6	0.0	15.5	9.2	10.4	1.0	0.0	0.0	59.1	1.4
	Mean	0.84	17.4	1.5	0.8	1.8	16.2	8.4	13.6	0.7	0.0	0.0	54.5	2.4
	SD	0.35	3.23	0.33	1.01	1.02	1.86	0.70	4.05	0.36	0.00	0.00	4.47	0.84
L. calcicola	3065	na	na	2.1	1.3	0.9	18.5	5.0	19.2	3.5	0.0	0.0	39.8	5.3
L. condensata	3118	na	na	2.1	2.1	0.7	25.1	7.2	18.7	4.2	0.0	0.0	28.3	2.3
L. fendleri	2997	0.55	30.5	1.6	0.4	1.7	18.7	8.7	16.8	1.1	1.1	0.4	45.9	3.6
	3068	na	na	3.4	1.7	2.1	28.2	12.6	21.8	0.2	0.0	0.0	25.1	2.2
	3343i*	0.65	17.6	0.9	0.5	2.4	15.0	6.4	11.1	1.2	0.5	0.4	57.5	4.1
	4001i*	0.69	21.6	1.2	0.6	2.3	15.6	8.0	12.3	1.0	0.5	0.0	55.5	3.0
	4002i*	0.56	24.8	1.3	0.0	2.5	16.7	8.6	12.9	1.0	0.0	0.0	54.5	2.6
	4003i*	0.58	na	1.3	0.0	2.3	16.2	7.7	13.3	1.0	0.0	0.0	55.1	3.2
	4005i*	0.71	22.7	1.7	0.0	2.2	15.9	8.5	13.3	0.8	1.5	0.0	53.3	2.8
	4006i*	0.57	22.7	1.3	0.6	2.0	14.6	7.3	13.7	0.9	0.0	0.0	55.9	3.8
	4007*	0.53	25.1	1.5	0.7	2.2	14.8	8.0	13.1	0.9	0.0	0.0	55.7	3.0
	4008i*	0.60	17.5	1.4	0.6	2.4	15.8	7.7	14.2	1.0	0.0	0.0	53.9	3.0
	4015i*	0.70	21.9	1.3	0.0	2.6	18.2	8.3	13.5	1.2	0.0	0.0	52.3	2.7
	4016i*	0.61	20.2	1.4	0.5	2.6	17.2	10.0	11.7	1.1	0.4	0.0	53.1	2.1
	4024i*	0.63	22.5	1.2	0.5	2.0	14.7	6.3	13.3	0.9	0.4	0.0	56.6	4.2
	4027i*	0.67	20.0	1.4	0.5	2.2	16.9	8.4	13.1	1.0	0.4	0.0	53.5	2.6
	4042i*	0.60	19.0	1.4	0.0	2.5	18.4	8.2	13.1	1.1	0.0	0.0	52.6	2.6
	4043*	0.50	19.9	1.3	0.5	2.3	17.1	7.0	13.3	1.1	0.0	0.0	53.6	3.8
	4043i*	0.60	20.4	1.1	0.0	2.6	16.1	6.9	14.6	0.9	0.0	0.0	54.3	3.6
	4044*	0.60	15.1	1.7	0.6	2.9	20.1	9.2	13.5	1.1	0.5	0.1	47.8	2.6
	4044i*	0.55	14.3	1.6	0.6	2.7	18.1	8.5	12.9	1.0	0.5	0.2	49.8	3.0
	4045*	0.55	12.9	2.3	0.8	3.0	20.7	8.7	15.2	1.0	0.5	0.5	44.6	3.0
	4045i*	0.60	15.7	1.3	0.0	2.5	16.4	7.8	13.0	1.2	0.0	0.0	54.8	3.1
	4046*	0.50	14.6	1.7	0.5	2.8	17.7	9.4	13.9	1.0	0.5	0.0	48.4	2.8
	4047*	0.60	17.8	1.0	0.0	2.3	14.8	6.7	12.5	1.4	0.0	0.0	58.2	3.2
	4047i*	0.55	19.5	1.6	0.0	2.9	18.8	9.3	13.7	1.1	0.0	0.0	50.5	2.2
	4048i*	0.65	13.4	2.0	0.0	3.0	20.6	10.5	13.6	1.1	0.0	0.0	47.7	1.6
	4049i*	0.60	20.9	1.6	0.6	2.8	16.9	8.6	14.0	1.0	0.0	0.0	52.0	2.5
	4050*	0.50	17.0	1.3	0.0	2.6	17.2	8.5	10.3	1.1	0.0	0.0	57.0	2.0
	4056i	0.75	23.3	1.9	0.0	1.8	14.0	7.0	12.9	0.0	0.0	0.0	57.3	5.2
	4058i*	0.65	25.0	1.5	0.0	1.6	21.0	6.5	16.9	1.0	1.5	0.8	44.3	4.9
	4061i*	na	19.8	1.6	0.0	2.9	21.8	8.8	15.7	1.2	0.0	0.0	46.0	2.0
	4062*	na	na	1.7	0.0	3.1	19.0	10.0	13.9	1.1	0.0	0.0	49.0	2.1
	4062i*	0.35	9.8	1.7	0.0	1.8	20.5	10.3	15.4	1.2	0.0	0.0	47.6	1.9
	Mean	0.60	19.5	1.5	0.3	2.4	17.7	8.4	13.8	1.0	0.3	0.1	51.4	3.0
	SD	0.08	4.41	0.45	0.38	0.40	2.85	1.36	2.01	0.26	0.42	0.18	6.24	0.85
L. garrettii	3197	na	na	2.2	1.4	2.1	21.5	12.0	13.0	0.2	0.0	0.0	44.0	1.2
L. gordonii	2911	0.50	19.7	1.8	0.0	1.7	21.8	6.3	8.6	0.0	0.0	0.0	55.8	1.9
	2914	0.55	28.5	1.6	0.0	1.5	22.9	4.9	7.6	0.0	0.0	0.0	56.4	2.4
	2914i	0.50	15.2	1.8	1.0	1.4	22.5	6.0	10.8	1.0	0.0	0.0	52.7	2.8
	2916	0.60	30.4	1.6	0.0	1.4	23.2	4.8	8.4	0.0	0.0	0.0	55.1	2.8
	2917	0.85	22.1	1.6	0.0	1.6	21.3	4.6	9.3	0.0	0.0	0.0	55.6	3.7
	2917i	na	na	3.3	0.0	0.0	27.4	10.8	10.6	0.0	0.0	0.0	47.9	0.0
	2936	0.60	27.0	1.6	0.0	1.5	24.8	5.6	7.9	0.0	0.0	0.0	54.1	2.2
	2938	0.55	26.8	1.5	0.0	1.4	24.4	4.8	7.9	0.0	0.0	0.0	54.8	2.8
	2939	0.60	27.8	1.5	0.0	1.4	22.6	4.5	8.0	0.0	0.0	0.0	56.6	3.2
	2939i	0.58	27.8	1.4	0.6	1.5	20.3	4.8	7.4	1.0	0.5	0.0	59.9	2.5
	3001	0.40	na	1.0	0.4	2.7	11.6	6.5	5.8	1.2	0.8	0.0	68.3	0.6
	3003	0.40	4.9	4.7	3.8	2.5	35.3	12.0	11.6	0.0	0.0	0.0	30.0	0.0
	3010	0.30	na	3.7	2.8	2.2	29.6	9.5	10.5	0.0	0.0	0.0	41.7	0.0
	3010i	0.55	14.7	1.7	0.8	1.3	20.1	5.6	10.9	1.0	0.0	0.0	56.0	2.6
	Mean	0.54	22.3	2.1	0.7	1.6	23.4	6.5	9.0	0.3	0.1	0.0	53.2	2.0
	SD	0.13	7.89	1.06	1.18	0.64	5.32	2.46	1.69	0.49	0.24	0.00	8.86	1.27

TABLE 2. Continued.

Species	Accession no.	Seed mass (mg)	Oil (%)	Fatty acid composition (%)[a]										
				16:0	16:1	18:0	18:1	18:2	18:3	20:1	18:1-OH	18:2-OH	20:1-OH	20:2-OH
L. gracilis	2921	na	28.9	1.3	0.0	1.1	9.3	3.8	3.9	0.5	0.0	0.0	68.8	0.0
	2921i	0.60	17.4	1.8	1.0	1.5	13.6	6.8	7.0	0.9	3.5	0.0	63.1	0.9
	2926	na	28.6	1.3	0.0	1.1	8.5	4.1	4.4	0.4	0.0	0.0	69.1	0.7
	2926i	na	17.7	1.8	0.8	1.2	15.3	9.5	3.4	0.7	0.0	0.0	63.6	0.3
	2928	na	18.0	1.5	0.0	1.3	17.4	6.0	7.7	0.0	0.0	0.0	59.4	2.5
	2928i	0.50	19.8	1.8	1.0	1.6	18.8	4.7	8.2	0.5	0.0	0.0	59.8	4.3
	Mean	0.55	22.1	1.5	0.4	1.2	12.8	6.0	5.3	0.5	0.6	0.0	64.8	0.9
	SD	0.07	5.49	0.26	0.52	0.20	4.21	2.14	2.10	0.30	1.43	0.00	4.21	1.65
L. hemiphysaria	3179i	1.15	25.9	1.4	0.9	0.8	13.5	10.5	14.1	0.8	0.0	0.0	56.6	1.4
L. hitchcockii	3026	2.30	30.0	1.4	0.5	1.1	19.7	8.8	11.6	1.3	1.4	0.4	51.7	2.0
L. inflata	4063i*	2.30	16.0	1.3	0.0	1.9	14.7	15.4	5.7	1.0	2.0	0.0	57.4	0.0
L. intermedia	3024	na	na	2.2	1.9	1.7	22.9	12.1	10.5	0.0	0.0	0.0	46.7	1.0
	3029	na	na	2.5	2.1	1.1	22.4	10.3	12.6	0.0	0.0	0.0	46.9	1.3
	3029i	0.80	18.8	2.1	1.2	0.9	20.1	6.3	16.1	0.8	0.0	0.0	49.3	3.4
	3033	1.30	26.6	1.7	0.7	0.9	16.6	9.0	15.8	0.0	0.0	0.0	51.3	2.4
	4055i	1.60	26.5	1.2	0.0	1.5	20.8	6.7	10.1	1.3	0.0	0.0	54.4	2.1
	Mean	1.23	24.0	1.9	1.2	1.2	20.6	8.9	13.0	0.4	0.0	0.0	49.7	2.0
	SD	0.40	4.45	0.50	0.86	0.37	2.49	2.45	2.82	0.60	0.00	0.00	3.22	0.94
L. ludoviciana	3042	1.20	28.3	1.6	0.7	1.3	19.4	8.9	13.2	1.2	1.0	0.0	50.0	2.6
	3042i	1.10	20.1	1.7	1.0	1.0	19.4	6.3	17.8	1.0	0.0	0.0	47.6	4.2
	3060	na	na	2.2	1.7	0.7	17.7	5.9	21.0	7.4	0.0	0.0	28.6	3.4
	3060i	na	18.8	1.6	0.7	0.0	19.4	3.0	21.6	0.9	5.9	10.8	28.4	7.3
	3062	0.50	na	2.2	1.7	0.6	16.7	5.8	22.0	8.5	0.0	0.0	26.4	3.1
	3063	na	na	1.9	1.9	0.6	19.2	5.8	20.2	8.7	0.0	0.0	25.6	3.2
	3084	na	na	1.9	1.5	1.3	15.7	6.9	21.1	0.0	0.0	0.0	46.4	4.4
	3116	na	na	4.3	4.9	1.3	28.3	10.0	16.7	2.8	0.0	0.0	22.5	1.8
	3132	na	na	4.5	4.0	1.6	33.1	10.3	16.7	1.5	0.0	0.0	19.5	1.1
	3133	0.50	na	5.0	4.7	0.0	36.3	10.7	20.4	0.0	4.5	2.8	15.5	0.0
	Mean	0.83	22.4	2.7	2.3	0.8	22.5	7.4	19.1	3.2	1.1	1.4	31.1	3.1
	SD	0.38	5.16	1.35	1.63	0.55	7.30	2.51	2.85	3.55	2.18	3.42	12.39	2.00
L. mexicana	3344i*	1.22	12.9	1.5	0.6	2.1	17.5	10.6	8.6	0.8	0.0	0.0	56.2	1.3
L. montana	3178i	0.60	24.8	1.5	0.8	1.0	19.9	5.7	16.5	0.9	0.0	0.0	50.4	3.4
L. multiceps	3186i	0.60	19.2	1.6	0.8	2.2	18.0	7.1	13.7	1.1	0.0	0.0	50.7	3.4
L. navajoensis	4057i	1.10	27.4	1.5	0.0	1.3	21.3	8.2	12.3	1.2	0.0	0.0	51.0	2.3
L. occidentalis	3195	na	17.0	1.4	0.0	2.6	19.7	9.1	8.5	0.8	0.0	0.0	56.8	1.2
L. ovalifolia	2412	na	15.9	1.4	0.0	1.3	15.0	10.6	11.3	0.9	1.2	0.0	56.6	1.8
	2913	2.00	20.5	1.5	0.0	1.5	19.4	7.3	15.3	0.4	0.0	0.0	47.0	4.9
	2913i	1.00	11.2	2.5	1.0	1.7	24.8	11.6	12.3	1.1	0.0	0.0	41.7	2.3
	2919	1.35	19.1	1.6	0.0	1.2	15.1	9.3	13.5	0.0	0.0	0.0	54.1	2.9
	2920	1.50	22.5	1.3	0.0	1.3	16.5	10.0	12.4	0.0	0.0	0.0	54.1	1.9
	2920i	na	18.2	1.6	0.0	1.3	16.4	10.8	12.0	1.1	0.0	0.0	54.8	2.2
	2922	1.30	15.9	1.8	0.0	1.6	16.8	9.3	13.2	0.0	0.0	0.0	52.4	2.5
	2922i	1.55	9.8	2.1	0.0	1.2	16.8	11.1	15.8	0.0	0.0	0.0	50.5	1.2
	2924	1.55	18.7	1.8	0.0	1.7	20.7	7.5	14.9	0.0	0.0	0.0	46.6	4.2
	2932	1.85	16.8	1.7	0.0	1.4	19.0	7.9	14.5	0.0	0.0	0.0	49.8	3.3
	2934	1.65	17.2	1.7	0.0	1.6	16.5	8.9	11.6	0.0	0.0	0.0	53.8	2.3
	2934i	2.15	12.3	1.8	1.0	1.3	17.7	7.5	17.9	0.0	0.0	0.0	49.1	3.8
	2935	1.70	19.5	1.5	0.0	1.4	16.9	9.9	13.6	0.3	0.0	0.0	51.3	2.7
	2935i	2.25	15.4	1.3	0.0	1.0	14.6	8.9	14.3	1.0	0.0	0.0	55.5	3.3
	2937	1.75	19.3	1.5	0.0	1.3	18.8	6.9	16.7	0.0	0.0	0.0	47.1	5.4
	Mean	1.66	16.4	1.7	0.1	1.4	17.4	8.9	14.4	0.3	0.0	0.0	50.6	3.1
	SD	0.35	3.53	0.32	0.34	0.21	2.61	1.50	1.93	0.46	0.32	0.00	4.11	1.18
L. pallida	3219i	0.90	20.7	1.9	0.0	1.3	4.9	5.4	4.4	1.1	1.4	0.0	79.8	0.0
L. parviflora	3095	na	na	2.4	2.1	1.5	22.8	16.2	10.3	0.0	0.0	0.0	42.1	0.6
	3103	2.40	na	1.7	1.0	1.1	15.2	14.6	12.8	0.0	0.0	0.0	50.8	1.2
	Mean			2.1	1.6	1.3	19.0	15.4	11.6	0.0	0.0	0.0	46.5	0.9
	SD			0.5	0.8	0.3	5.4	1.1	1.8	0.0	0.0	0.0	6.2	0.4
L. rectipes	2996i	0.63	32.2	1.9	0.8	1.4	21.4	9.6	11.8	1.1	0.7	0.0	50.0	1.5
L. tuplashensis	3220i	1.35	21.6	1.4	0.8	0.8	19.3	8.8	15.6	0.8	2.9	1.0	46.1	2.1
L. valida	4088	0.70	na	2.7	1.2	1.8	25.4	6.7	10.8	1.1	0.0	0.0	48.2	2.1

[a] 16:0 = palmitic acid; 16:1 = palmitoleic acid; 18:0 = steric acid; 18:1 = oleic acid; 18:2 = linoleic acid; 18:3 = linolenic acid; 20:1 = eicosenoic acid; 18:1-OH = ricinoleic acid; 18:2-OH = densipolic acid; 20:1-OH = lesquerolic acid; 20:2-OH = auricolic acid.

TABLE 3. Seed mass, percent oil content, and fatty acid composition of auricolic- and densipolic-acid-rich *Lesquerella* species. ''Na'' indicates data not available, ''i'' indicates seed was increased at USWCL.

Species	Accession no.	Seed mass (mg)	Oil (%)	Fatty acid composition (%)[a]										
				16:0	16:1	18:0	18:1	18:2	18:3	20:1	18:1-OH	18:2-OH	20:1-OH	20:2-OH
L. auriculata	3008	na	na	4.9	2.5	6.5	39.0	4.4	11.1	1.7	0.0	0.0	4.3	18.5
	3009	0.50	na	4.3	1.5	6.3	38.6	2.9	9.9	1.4	0.0	0.0	7.6	21.8
	3009i	0.65	19.3	4.9	1.1	8.5	40.7	3.6	20.1	4.0	0.0	0.0	4.4	12.8
	3011	na	na	4.2	1.2	6.3	41.2	3.4	8.1	1.6	0.0	0.0	8.1	17.4
	3011i	0.55	16.4	5.4	1.6	10.3	46.6	2.6	17.4	3.7	0.0	0.0	2.2	10.2
	Mean	0.57	17.9	4.7	1.6	7.6	41.2	3.4	13.3	2.5	0.0	0.0	5.3	16.1
	SD	0.06	1.48	0.44	0.49	1.59	2.86	0.62	4.61	1.12			2.22	4.14
L. densipila	2984	0.70	20.0	7.5	0.0	3.8	22.9	3.0	21.0	0.0	8.0	33.7	0	0.0
L. katheryn	4087i	na	18.8	6.6	1.0	6.1	34.2	2.3	23.6	0.0	2.1	23.3	0.0	0.0
L. lescurii	2897	0.55	na	5.3	0.9	3.5	29.0	2.0	16.1	0.0	7.8	34.8	0.0	0.0
	2898	0.60	14.6	7.2	na	5.8	36.4	3.5	18.3	0.0	0.0	20.5	0.0	0.0
	Mean	0.58		6.3		4.7	32.7	2.8	17.2	0.0	3.9	27.7	0.0	0.0
	SD	0.04		1.34		1.63	5.23	1.06	1.56		5.52	10.11		
L. lyrata	2999	na	na	9.7	na	5.0	42.5	6.5	21.3	0.0	0.0	14.9	0.0	0.0
	3000	na	25.8	7.2	na	6.6	32.2	2.4	19.1	0.0	0.0	26.9	0.0	0.0
	3000i	0.80	19.0	8.2	1.3	6.0	34.5	3.0	23.2	0.0	1.9	19.9	1.1	0.0
	Mean		22.4	8.4		5.9	36.4	4.0	21.2	0.0	0.6	20.6	0.4	0.0
	SD		4.79	1.26		0.80	5.41	2.21	2.05		1.10	6.03	0.64	
L. perforata	2903i	1.15	27.4	5.5	1.0	5.5	29.1	1.7	14.7	0.0	6.9	35.2	0.0	0.0
L. stonensis	2929	na	na	8.1	1.9	7.7	42.4	3.0	21.1	0.0	0.0	15.8	0.0	0.0

[a] 16:0 = palmitic acid; 16:1 = palmitoleic acid; 18:0 = steric acid; 18:1 = oleic acid; 18:2 = linoleic acid; 18:3 = linolenic acid; 20:1 = eicosenoic acid; 18:1-OH = ricinoleic acid; 18:2-OH = densipolic acid; 20:1-OH = lesquerolic acid; 20:2-OH = auricolic acid.

new accessions may introduce additional diversity for seed mass, which is an important component of overall yield.

A comparison of the mean seed mass of several *Lesquerella* species reported in this study to those reported previously by Dierig et al. (1996) indicated that the mean seed mass of *L. argyraea* collected in Mexico was 0.84 mg compared to 0.60 mg reported for collections of this species from Texas. Our accessions of *L. gordonii* from Oklahoma had a mean seed mass of 0.54 mg compared to a mean of 0.87 mg reported for collections from Arizona and New Mexico. Our accessions of *L. intermedia* from Arizona and Utah had a mean seed mass of 1.23 mg compared to 0.98 mg reported for collections from Arizona. The one accession of *L. tuplashensis* has a seed mass of 1.35 mg. Although the taxonomy of this species is somewhat controversial (Rollins et al., 1995; Al-Shehbaz and O'Kane, 2002) it is probably a sister taxon of *L. douglasii* Wats. The reported seed mass for *Lesquerella douglasii* was 1.56 mg, which is very close to our observed value for *L. tuplashensis*.

Seed masses within species of *Physaria* were highly variable (Table 4). For example, they ranged from 2.14–3.00 mg in *P. acutifolia* Rydb. to 2.44–4.61 mg in *P. chambersii* Rollins, 1.52–2.18 mg in *P. eburnifolia* Rollins, 2.26–3.60 mg in *P. floribunda* Rydb., 4.38–5.83 mg in *P. lepidota*, 1.53–2.26 mg in *P. repanda* Rollins, and 1.34–2.14 mg in *P. vitulifera* Rydb. The only accession of *P. newberryi* Gray had a seed mass of 1.84 mg, which is much less than the mean of 5.4 mg reported by Dierig et al. (1996) for two collections from Arizona. While species of *Physaria* may have seed masses 2–10 times that of *L. fendleri*, they only have 2–4 ovules per locule compared to the 10–16 ovules per locule for *L. fendleri* (Rollins, 1993), which when combined with fewer fruits per plant tend not to match the oil yields possible in *L. fendleri*.

Seed oil content—The percent seed oil content of our collections of *Lesquerella* and *Physaria* (Tables 2–4) fall within the ranges reported from other studies (Hayes et al., 1995; Dierig et al., 1996). Densipolic-acid-rich species and auricolic acid-rich species reported by Hayes et al. (1995) contained 23–29% and 33% oil, respectively. The densipolic acid-rich species collections presented here ranged from 14.6 to 27.4% oil (accession nos. 2898, and 2903i, respectively), and the auricolic-acid-rich species, *L. auriculata*, ranged from 16.4 to 19.3% oil (accession nos. 3011i, and 3009i, respectively) (Table 3).

The oil content of our accessions of lesquerolic-acid-rich species ranged from a high of 32.2% for *L. rectipes* Woot. & Standl. (accession no. 2996i) to a low of 4.9% for *L. gordonii* (accession no. 3003) (Table 2). The low oil content of accession 3003 was probably due to immature seed or to an unreliable datum. Because only one or two collection trips to a locality were made, the acquisition of mature seeds from the field was not always possible, and fruits with developing seeds were collected regardless of their maturity. The deposition of seed oil follows a sigmoidal pattern during seed development (Miquel and Browse, 1995). The initial phase occurs right after flowering where TAG is present only in trace amounts and the fatty acid composition is similar to that of vegetative tissues. The middle or growth phase has a gradual and then rapid accumulation of TAG in parallel with an increase of characteristic FAs and seed growth. The final phase is seed maturity with no mass gain and cessation of TAG accumulation. Thus, it would be expected that seed harvested before the rapid accumulation of TAG would contain only low amounts of oil. While temperature might have an effect on seed oil quantity and quality, Hunsaker et al. (1998) demonstrated that irrigation treatments on *L. fendleri* did not affect the seed oil content or lesquerolic content of the oil, but the seed yield and dry matter were affected.

Every species of *Lesquerella* with more than one accession had a mean oil content of $<25\%$ and only three (Nos. 2297, 4007, and 4058i) of the 27 accessions of *L. fendleri* contained $\geq 25\%$ oil (Table 2). The oil content in *L. fendleri* in this study ranged from 9.8% in accession 4062i to 30.5% in accession

2997. The mean of these accessions was 19.5% oil. Accession 2997, from Arizona, had the highest reported oil content for a wild collection of the species, comparable to that of our selected high oil content breeding line (Dierig et al., 2001). In a study comparing 82 collections of *L. fendleri* from Arizona, New Mexico, and Texas, no significant differences in the average oil content were found among the accessions from the different states nor between the original accessions and cultivated accessions at the USWCL (Dierig et al., 1996). This indicates that there is more intrapopulation variation than interpopulation variation in *L. fendleri* and that the oil content in this species is not noticeably affected by the environment in its natural range.

Species of *Physaria* had seed oil contents ranging from 18.9 (accession No. 3154) to 35.4% (accession No. 3085), with a mean for the genus of 27.4% (Table 4). The mean oil content of *P. floribunda* is 30.7%, which is similar to earlier reports of 31 and 26% (Hayes et al., 1995; Dierig et al., 1996). The one accession of *P. newberryi* has an oil content of 25.2%, which is lower than a mean of 30.8% from two previously reported Arizona collections (Dierig et al., 1996). For comparison to the values given here, the oilseed cultivars of *Brassica* species (i.e., *B. juncea*, *B. napus*, and *B. rapa*) contain over 40% oil (Downey, 1983) and 360 accessions of *Arabidopsis thaliana* were reported to have a modal oil content of 38%, with a range of 33–43% (O'Neill et al., 2003).

The percent oil content of seeds can be increased in two ways. One is direct, by increasing the overall oil content of the embryo. The other is indirect, by increasing the proportion of the seed that is the embryo with a concomitant decrease in the seed coat proportion (Knowles, 1983). We did not differentiate between the two measures of seed oil content. Our goal is to increase the overall oil content of the embryo, since the seed coat (i.e., the resulting meal after oil extraction) is a valuable co-product of the oil and thin seed coats can often result in reduced shelf-life, and early or poor germination of the seeds.

Fatty acid composition—Fatty acid compositions of *Lesquerella* and *Physaria* species are given in Tables 2–4. For some accessions, analyzed before 1997, the data for palmitoleic, ricinoleic, and densipolic acids were lost; therefore ''na'' (data not available) was entered in the column for each occurrence. Levels of densipolic acid in the six densipolic-acid-rich species examined ranged from 14.9 to 35.2% (Table 3). These values are lower than the 41–47% reported by Hayes et al. (1995). Coupled with the low oil content for these species reported above, this indicates that the seeds were probably not fully mature. The three accessions of *L. auriculata* had a mean auricolic acid content of only 16.1% with a range of 10.2–21.8%. This mean is half of that given in two previous reports (Kleiman et al., 1972; Hayes et al., 1995).

Lesquerolic acid contents of most lesquerolic-acid-rich species averaged from 40 to 55% (Table 2). It is probable that the low level (28.3%) found in *L. condensata* Nels. was the result of immature seed or unreliable datum. However, because little seed was available the analysis could not be repeated. The content of lesquerolic acid found in *L. fendleri* ranged from 25.1 (accession No. 3068) to 58.2% (accession No. 4047) with a mean of 51.4%. This mean is slightly higher than the mean values reported from previous germplasm collections from Arizona, New Mexico, and Texas (Dierig et al., 1996). All but three of the 27 *L. fendleri* accessions (Nos. 2997, 3068, and 3343) were from Mexico, and considerable inter- and intrapopulation morphological polymorphism was observed within its wide geographic range. This morphological variation, in addition to the range of oil characteristics in these collections of *L. fendleri*, should provide a large amount of genetic variability for our breeding program. Five of the wild accessions of *L. fendleri* (Nos. 4043, 4044, 4045, 4047, and 4062) that were analyzed were also increased at the USWCL. Two accessions (Nos. 4047, and 4062) had a lower percentage of lesquerolic acid content than their respective increased collection, one had a nearly identical content (No. 4043), and two accessions (Nos. 4044, and 4045) had a higher content.

All species of *Physaria* have oils rich in lesquerolic acid, with ranges of 31.7–54.7% (accessions No. 3208, and No. 3086 respectively) (Table 4). The high values of lesquerolic acid combined with the high oil content and seed mass of species of *Physaria* are promising for its future as an alternative source of HFAs for cooler climates and higher elevations.

Hayes et al. (1995) called the oil of *L. ludoviciana* (Nutt.) Wats., a ''most unusual'' oil for the genus, because they found it contained a mixture of ricinoleic (13%), densipolic (10%), lesquerolic (27%), and auricolic (4%) acids. With the exception of three accessions (Nos. 3042, 3060i, and 3133), our collections contained no ricinoleic or densipolic acids. Interestingly, the only accession (No. 3060i) that had significant amounts of both ricinoleic and densipolic acids was increased at the USWCL, while the wild seed from which it came from did not contain these fatty acids. This raises the possibility that the fatty acid profile of this species may be plastic depending on the environment. However, wild and cultivated seed from accession 3042 were not significantly different from each other in their fatty acid profile.

The TAG molecules of *L. angustifolia*, *L. argyraea*, *L. gordonii*, *L. gracilis*, and *L. inflata* Rollins & Shaw contain lesquerolic acid at all three positions of the glycerol backbone, making it possible for the oils of these species to contain >66% lesquerolic acid (Hayes et al., 1995). *Lesquerella fendleri* oil is theoretically limited to a maximum of 66% total lesquerolic acid because it cannot include lesquerolic acid in the *sn*-2 position of the TAG molecule. *Lesquerella pallida*, however, must have the ability to include lesquerolic acid at all three TAG positions, because its oil contains up to 79.8% lesquerolic acid (Table 2). We are currently trying to introgress this trait for the ability to include lesquerolic acid at the *sn*-2 position of the TAG molecule into *L. fendleri* through interspecific crosses. The more species that become available for crosses with this trait, the greater our likelihood of success of significantly increasing the quality of *L. fendleri* oil.

In summary, this study evaluated 99 accessions from 31 species of *Lesquerella* from throughout the United States and Mexico, as well as 41 accessions from 15 species of *Physaria* from the southwestern United States. Of these collections several species have potential for agronomic development as alternative sources of HFA. They could also be used as sources of genetic variability for oil content, seed yield or oil quality in the development of new cultivars of *L. fendleri*, which have the potential to be grown on 1.4 million acres of existing farmland in the southwestern United States (Van Dyne, 1997). Accessory to the new germplasm collections, our objective of developing a domestic source of HFAs will benefit from the application of new improvements in plant breeding, including marker-assisted selection, biotechnology, and screening techniques such as half-seed analysis—methods that should greatly decrease the length of domestication for *Lesquerella*.

TABLE 4. Seed mass, percent oil content, and fatty acid composition of *Physaria* species. "Na" indicates data not available, "i" indicates seed was increased at USWCL.

Species	Accession no.	Seed mass (mg)	Oil (%)	Fatty acid composition (%)[a]										
				16:0	16:1	18:0	18:1	18:2	18:3	20:1	18:1-OH	18:2-OH	20:1-OH	20:2-OH
P. acutifolia	3050	2.66	30.6	1.7	0.5	1.3	21.7	11.1	10.7	1.5	0.5	0.0	49.2	1.2
	3085	2.14	35.4	1.3	0.3	1.3	18.5	10.0	11.8	1.1	0.6	0.0	52.5	2.1
	3094	2.38	29.4	2.0	1.3	1.3	20.7	10.9	13.4	1.1	1.0	0.0	46.4	2.0
	3104	3.00	na	4.6	na	1.6	17.0	19.0	12.7	0.0	na	na	40.0	0.0
	3177	2.14	32.5	1.5	0.6	1.0	19.2	8.7	12.4	1.0	1.1	0.2	51.8	2.5
	3185	2.02	24.8	1.7	0.4	1.3	16.9	9.1	13.6	1.0	1.2	0.0	52.4	2.4
	3189	2.50	na	1.9	na	1.1	17.8	11.0	14.1	0.7	na	na	49.1	2.2
	3193	2.85	26.4	1.6	0.5	1.5	19.9	11.7	11.0	1.1	1.0	0.0	49.7	1.5
	4059	2.92	29.3	1.8	0.0	1.3	23.7	8.8	10.3	1.0	0.9	0.0	50.4	2.1
	Mean	2.51	29.8	2.0	0.5	1.3	19.5	11.1	12.2	0.9	0.9	0.0	49.1	1.8
	SD	0.37	3.6	1.0	0.4	0.2	2.3	3.1	1.4	0.4	0.3	0.1	3.9	0.8
P. alpina	3208	na	na	2.8	2.4	1.5	29.6	11.8	17.2	1.1	0.0	0.0	31.7	1.9
P. bellii	3105	3.04	31.1	1.2	0.4	1.1	19.4	8.1	13.0	1.3	0.5	0.0	51.9	2.5
	3106	2.98	24.9	1.4	0.5	1.0	16.4	9.7	12.5	1.0	1.0	0.2	53.7	2.6
	Mean	3.01	28.0	1.3	0.5	1.1	17.9	8.9	12.8	0.0	0.8	0.1	52.8	2.6
	SD	0.04	4.4	0.1	0.1	0.1	2.1	1.1	0.4	0.2	0.4	0.1	1.3	0.1
P. brassicoides	3122	2.30	28.7	1.6	0.3	0.9	17.5	8.6	14.7	1.0	1.3	0.4	50.0	3.7
	3130	na	na	2.7	1.8	1.1	32.4	9.4	16.4	0.0	0.0	0.0	33.1	3.3
	Mean			2.2	1.1	1.0	25.0	9.0	15.6	0.0	0.7	0.2	41.6	3.5
	SD			0.8	1.1	0.1	10.5	0.6	1.2	0.7	0.9	0.3	12.0	0.3
P. chambersii	3022	3.29	na	1.6	na	1.5	19.3	11.2	11.4	0.6	na	na	50.7	1.4
	3023	4.61	na	1.7	na	1.3	15.4	13.7	10.6	0.5	na	na	53.7	1.0
	3025	3.80	28.2	1.4	0.3	1.7	20.2	11.6	10.7	1.3	0.7	0.0	50.2	1.2
	3030	3.02	27.2	1.5	0.3	1.2	15.5	12.2	11.6	1.0	0.9	0.0	54.2	1.4
	3039	2.44	29.3	1.2	0.3	1.2	18.7	9.3	13.0	1.1	1.0	0.2	51.3	2.5
	3044	2.50	na	1.7	na	2.0	15.6	10.7	14.3	0.4	na	na	51.3	1.7
	3155	4.04	24.6	1.6	0.5	1.9	18.1	13.2	11.0	1.0	0.3	0.0	50	1.1
	Mean	3.39	27.3	1.5	0.4	1.5	17.5	11.7	11.8	0.8	0.7	0.1	51.6	1.5
	SD	0.81	2.0	0.2	0.1	0.3	2.0	1.5	1.4	0.3	0.3	0.1	1.7	0.5
P. dornii	3190	na	na	1.3	na	0.8	20.3	9	15.6	2.6	na	na	43.2	3.4
P. eburniflora	3120	2.18	27.7	1.4	0.5	0.8	22.1	8.2	13.9	1.0	1.4	0.8	46	3.8
	3121	1.52	na	1.8	na	0.9	22.1	8.3	16.2	0.9	0.8	na	43.7	3.3
	Mean	1.85	27.7	1.6		0.9	22.1	8.3	15.1	1.0	1.1		44.9	3.6
	SD	0.47		0.3		0.1	0.0	0.1	1.6	0.1	0.4		1.6	0.4
P. floribunda	3071	2.26	30.4	1.3	0.3	1.4	17.8	10.3	10.3	1.2	1.9	0.3	53.2	2.1
	3072	2.28	29.3	1.3	0.4	1.2	16.2	10.6	11.9	1.1	1.3	0.0	53.4	1.9
	3076	3.60	31.1	1.4	0.5	0.3	17.0	9.8	11.2	1.0	1.5	0.0	54	2.3
	3086	2.54	32.1	1.4	0.4	1.3	16.4	12.6	9.7	1.0	0.9	0.0	54.7	1.1
	3092	na	na	1.4	na	1.2	16.6	9.8	13.7	1.0	0.3	na	51.9	2.3
	Mean	2.67	30.7	1.4	0.4	1.1	16.8	10.6	11.4	1.1	1.2	0.1	53.4	1.9
	SD	0.63	1.2	0.1	0.1	0.4	0.6	1.2	1.6	0.1	0.6	0.2	1.0	0.5
P. lepidota	3018	5.83	29.0	1.5	0.3	1.5	18.9	13.8	8.6	1.0	0.4	0.0	52.7	0.8
	3020	4.38	24.6	1.7	0.3	2.1	21.2	14.9	7.7	1.3	0.8	0.0	48.5	0.7
	Mean	5.11	26.8	1.6	0.3	1.8	20.1	14.4	8.2	1.2	0.6	0.0	50.6	0.8
	SD	1.03	3.1	0.1	0.0	0.4	1.6	0.8	0.6	0.2	0.3	0.0	3.0	0.1
P. newberryi	3021	1.84	25.2	1.5	0.4	1.3	18.7	8.7	12.4	1.1	2.5	0.0	51	2.8
P. obcordata	3096	5.74	27.5	1.5	0.2	1.3	16.1	12.6	12.7	1.2	1.5	0.0	50.9	1.4
P. repanda	3167	1.53	na	1.8	na	1.6	23.3	11.1	12.0	1.1	0.3	0.0	44.4	2.0
	3182	2.26	na	2.1	na	1.4	19.8	9.9	14.5	0.6	0.0	0.0	46.5	2.4
	Mean	1.90		2.0		1.5	21.6	10.5	13.3	0.9	0.2	0.0	45.5	2.2
	SD	0.52		0.2		0.1	2.5	0.8	1.8	0.4	0.2	0.0	1.5	0.3

TABLE 4. Continued.

Species	Accession no.	Seed mass (mg)	Oil (%)	Fatty acid composition (%)[a]									
				16:0	16:1	18:0	18:1	18:2	18:3	20:1	18:1-OH	18:2-OH	20:1-OH	20:2-OH
P. saximontana	3153	1.66	23.6	1.4	0.6	0.8	19.1	6.5	16.2	1.2	0.9	0.0	48.6	4.8
P. stylosa	3196	3.20	28.6	1.7	0.4	1.6	16.3	12.3	10.4	0.9	1.5	0.2	53.1	1.7
P. vitulifera	3055	1.70	27.4	1.4	0.3	1.1	14.8	9.1	12.3	1.1	1.8	0.4	54.7	3.1
	3057	2.14	27.8	1.7	0.5	1.4	19.5	10.1	12.1	1.3	0.9	0.0	50.6	1.9
	3059	1.66	26.2	1.6	0.4	1.4	19.1	8.7	14.2	1.3	1.8	0.0	48.4	3.1
	3154	1.34	18.9	1.3	0.5	0.9	17.4	6.7	15.5	1.2	1.0	0.3	50.2	5.1
	Mean	1.71	25.1	1.5	0.4	1.2	17.7	8.7	13.5	1.2	1.4	0.2	51.0	3.3
	SD	0.33	4.2	0.2	0.1	0.2	2.1	1.4	1.6	0.1	0.5	0.2	2.7	1.3

[a] 16:0 = palmitic acid; 16:1 = palmitoleic acid; 18:0 = steric acid; 18:1 = oleic acid; 18:2 = linoleic acid; 18:3 = linolenic acid; 20:1 = eicosenoic acid; 18:1-OH = ricinoleic acid; 18:2-OH = densipolic acid; 20:1-OH = lesquerolic acid; 20:2-OH = auricolic acid.

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