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Echium: A Source of Stearidonic Acid Adapted to the Northern Great Plains in the US

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The genus *Echium*, (Boraginaceae) has Mediterranean and Macaronesian origin (Guil-Guerrero et al. 2001). *Echium plantagineum* L., also known as viper's bugloss, blueweed, and snake's flower, has spread widely throughout the world and has become an invasive weed in Australia, and South America. *Echium plantagineum* is an annual plant, but occasionally can be biennial. Plants form a rosette with oval leaves at the beginning of the season. Several stems are produced at the base of the rosette. Stems have long, white trichomes or hairs. Flowers uncurl on an inflorescence called a cyme that has as many as 30 flowers. Flowers are perfect, blue, purple, sometimes white, and pink, trumpet-shaped, and sessile (IENICA 2002). One to four nutlets or seeds are produced at the calyx. Seeds are dark brown or grey, small only 3 mm long, and have a triangular shape with three sides (Nicholls 2000). The plant grows to about 70 to 120 cm in height (Fig. 1).

Echium seed oil varies from 200 to 250 g kg^{-1} (Clough 1993). The oil contains 9% to 16% of stearidonic acid (6,9,12,15 octadecatetraenoic acid) SDA (18:4n-3), a highly unsaturated omega-3 fatty acid. Stearidonic acid is very uncommon in higher plants, but very important in human nutrition because SDA is an intermediate in the biosynthesis of eicosapentanoic (EPA) and docosahexaenoic (DHA) acids. Both of these omega-3 fatty acids, present in fish oil, are required in human diets for cell membrane functioning and good health (Coupland

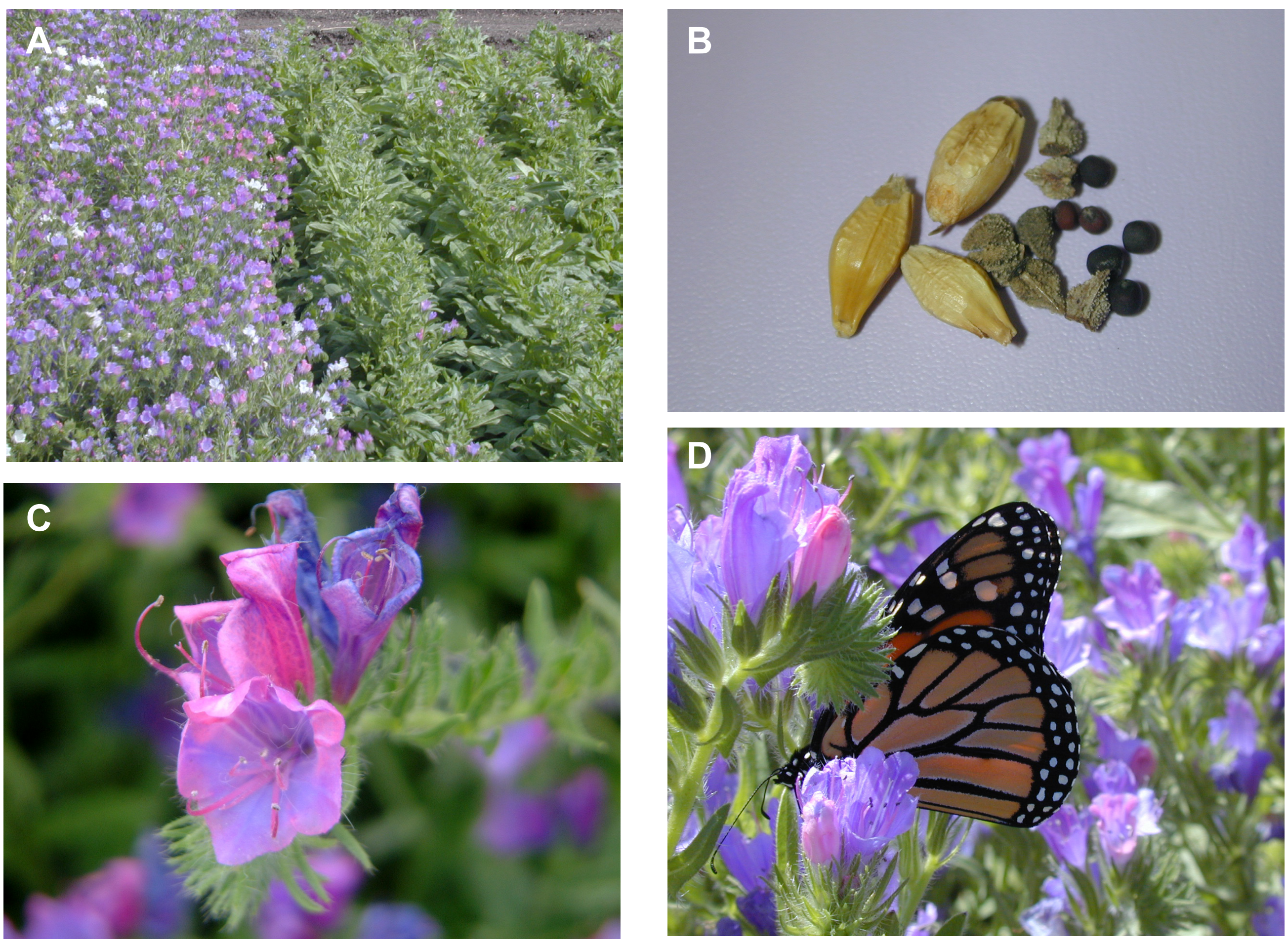

Fig. 1. (A) Planting dates at Prosper, North Dakota, 23 May (left), 6 June (right). (B) Echium seed compared to barley (*Hordeum vulgare* L.) (left) and canola (*Brassica napus* L.) (right). (C) Echium inflorescence. (D) Monarch butterfly (*Danaus plexippus* L.) visiting echium.

and Hebard 2002). Higher intake of omega-3 fatty acids has been positively associated with the prevention of cardiovascular diseases, arthritis, inflammatory diseases, and autoimmune diseases in humans (Simopoulos 1999).

Stearidonic acid is found in other *Echium* species (*E. vulgare* L.), hemp seed (*Cannabis sativa* L., Cannabaceae) (2%–3%) (Callaway et al. 1996), and blackcurrant seed (*Ribes nigrum* L., Grossulariaceae) (about 2%) (Clough 1993). Echium oil also contains gamma-linolenic acid (6,9,12 octadecatetraenoic acid) GLA (18:3n-3), and alpha-linolenic acid (9,12,15 octadecatetraenoic acid) ALA. Echium seed oil has a unique ratio of omega-3 to omega-6 fatty acids not present in any other plant.

Echium oil has many potential uses in the pharmaceutical industry for treatment of eczema, acne, and other skin disorders and in the cosmetic and personal care products industry. Echium oil, applied topically, reduces skin wrinkles and protects and moisturizes the skin from sun exposure (Nicholls 2000). Currently there are many lotions and creams, sold online in the USA, that include echium oil as one of the ingredients. Echium is grown commercially in the UK and Europe despite being known as an invasive weed (Paterson's curse) in Eastern Australia (Burdon and Brown 1986). Experimental production has been conducted in New Zealand and Chile.

The current market for echium oil and prices is unknown since it is used as a source of both, SDA and GLA and the current retail US market is highly fragmented by the end product marketer. Echium oil price can be estimated based on prices for evening primrose (*Oenothera biennis* L., Onagraceae) and borage (*Borago officinalis* L., Boraginaceae) oils, most common sources of GLA in the market. Evening primrose and borage oil prices range from \$10 to 15 kg and \$30 to 35 kg, respectively (Lindemann and Merolli 2006). Echium seed yield and oil content is similar to borage, although the GLA content is half of that from borage oil. According to this echium oil should range between \$15 to \$20 kg.

The objective of this study was to evaluate the seed yield potential and oil quality of *E. plantagineum*. Emphasis is placed on SDA content, at different environments and seeding dates in North Dakota.

MATERIALS AND METHODS

Evaluation of potential echium adaptation was performed at Carrington, Langdon, Minot, and Prosper, North Dakota from 2002 to 2004 with subsequent evaluation of seeding date effects at Prosper in 2005 and 2006. Echium seed from the UK was provided by Technology Crops International. Also, echium seed from wild populations was collected in Chile between latitude 35° to 41°S and were evaluated at Prosper in 2005 and 2006. The experimental design was a randomized complete block with four replicates. Experimental units consisted of six rows spaced 30 cm apart and 5 m in length. Seeding rate and seeding depth were 22 kg ha^{-1} and 13 mm, respectively. Seeding date was targeted for the last week of May at all locations. Days to 50% emergence was evaluated only at three locations, Langdon 2003, Prosper 2003, and Prosper 2004. Days to the beginning of flowering was evaluated at all locations. Biomass yield was calculated from a one meter square harvested area from each plot with plants cut at the soil surface. Plant height was measured from 10 plants right before swathing. Plant lodging was evaluated at most locations. Days from planting to harvest were determined for the Prosper 2005 and 2006 trials. Plots of echium were hand-swathed and threshed approximately 10 days later. Seeds were dried at 45°C and then cleaned before determining seed yield. Harvest index was calculated as the percent of dry seed weight over the total above ground dry biomass. Seed oil content was determined with a Newport 4000 Nuclear Magnetic Resonance (NMR) Analyzer, Oxford Institute Limited. Samples were dried in an oven at 110°C for 3 hr and then cooled to room temperature to equilibrate seed moisture content before the analysis. Fatty acid composition was determined with a gas chromatographer according to the standard method of the AOCS (Ackman 2002).

Statistical analyses were conducted by using standard procedures for a randomized complete block design (Steel and Torrie 1980). Means separation was performed by applying *F*-protected LSD comparisons at $P \leq 0.05$ level of significance.

RESULTS

Mean monthly rainfall and temperature are presented in Table 1. The days to flowering fluctuated from 31 to 49 days (Table 3). The average plant height fluctuated between 68 and 107 cm. At the North Dakota loca-

Table 1. Mean monthly growing season rainfall and temperature at four North Dakota locations.

	Minot			Carrington		Langdon			Prosper					
Month	2002	2005	30-yr avg	2002	30-yr avg	2002	2003	30-yr avg	2002	2003	2004	2005	2006	30-yr avg.
						Mean growing season rainfall (mm)								
May	37	82	58	14	63	24	74	60	41	137	128	64	41	68
June	93	255	76	70	96	144	73	85	96	83	13	161	12	91
July	43	47	64	77	79	28	39	81	107	41	101	34	66	82
Aug.	73	32	51	94	63	124	39	69	45	24	35	113	25	68
Sept.	7	7	45	12	47	33	32	42	41	34	66	104	95	54
Total	253	423	294	267	348	353	257	337	330	319	343	476	239	363
						Mean growing season temperature (°C)								
May	9	11	13	9	13	8	11	11	10	13	11	12	15	13
June	18	18	18	19	18	17	16	16	20	18	16	20	19	18
July	22	21	23	21	21	20	19	18	22	20	19	21	22	21
Aug.	19	19	19	18	20	18	20	18	20	21	16	19	20	20
Sept.	15	16	13	15	14	14	12	12	16	14	16	17	14	14

Table 2. Mean echium characters determined at several North Dakota locations.

Location	Year	Days to emergence	Days to flowering	Plant height (cm)	Plant lodging (%)	Biomass yield (t ha^{-1})	Seed yield (kg ha^{-1})	Harvest index (%)	Oil content (g kg^{-1})
Carrington	2002	--	31	68	--	9	213	3	--
Langdon	2002	--	43	93	--	11	63	1	--
	2003	11	42	101	76	11	315	3	--
Minot	2002	--	--	50	--	3	135	4	--
Prosper	2002	--	32	89	76	6	165	5	--
	2003	10	43	107	46	9	425	4	272
	2004	13	49	91	11	10	221	1	298

Table 3. Mean echium characters determined at Prosper and Minot, North Dakota.

Location	Year	Date	Stand (%)	Days to flowering	Plant height (cm)	Plant lodging (%)	Days to harvest	Seed yield (kg ha^{-1})	Oil content (g kg^{-1})
		1 June	80	39	99	98	90	302	270
Prosper	2005	17 June	90	42	128	95	97	222	266
Prosper	2006	23 May	100	43	104	95	92	322	268
		6 June	100	38	111	95	77	366	257
Minot	2005	15 June	--	--	69	--	--	266	229
LSD[z] [(Environment*date) (0.05)]			--	NS	NS	NS	NS	72	NS

[z]LSD only compares Prosper data from 2005 and 2006.

Table 4. Mean fatty acid content for echium grown at Prosper in 2003, 2004, and 2005.

Year	Seeding date	Fatty acid content (%)						
		Palmitic	Stearic	Oleic	Linoleic	GLA[z]	ALA	SDA
2003		6.8	3.7	15.5	14.8	11.3	30.7	13.5
2004		5.7	3.5	12.6	13.2	11.6	32.7	15.2
2005	June 1	7.8	5	15.4	15.2	10.2	31.3	12.9
	June 17	7.5	4.4	16.3	15.2	10.8	31.0	13.3
	LSD[y]	NS	0.6	NS	NS	0.6	NS	0.6

[z]GLA= Gamma-linolenic acid, ALA= alpha-linolenic acid, SDA=stearidonic acid.

[y]LSDs for palmitic, stearic, oleic, linoleic, and ALA acids compare only the two seeding dates at Prosper 2005 $P<0.05$. LSDs for GLA and SA compare all environments; seeding dates at Prosper 2005 were considered as separate environments for GLA and SDA analysis only.

tions, biomass ranged from 3 to 11 t ha^{-1} and seed yields from 63 to 425 kg ha^{-1} (Table 2). Greatest seed yield was observed at Prosper 2003 when rainfall was above normal and temperature was average (Table 1). Delayed seeding in 2005 reduced seed yield, but no effect was observed in 2006 (Table 3). The harvest index for echium is extremely low indicating little domestication and plant breeding improvement. High lodging of the crop after full bloom contributes to seed shattering, white mold [*Sclerotinia sclerotiorum* (Lib.) De Bary] infection, and poor seed yield. White mold was detected on echium plants with bleached stems, presence of sclerotia, and wilted appearance. This was previously reported in North Dakota by Del Rio et al. (2005).

Seed oil content was 272 and 298 g kg^{-1} at Prosper in 2003 and 2004, respectively (Table 2). Seeding date did not affect seed oil content in any year (Table 3). The GLA and SDA contents were 11.3% and 11.6% and 13.5% and 15.2%, respectively, at Prosper in 2003 and 2004, respectively, no significant differences were observed (Table 4). Oil yield is approximately 116 kg ha^{-1} if we multiply seed yield (425 kg ha^{-1}) by oil content (27.2%). Gross return for farmers would be approximately $1,740/ha at a price of $15 kg^{-1} of oil.

Two of the wild echium populations (lines) collected in Chile that were grown in North Dakota failed to flower and several others flowered late in the season and produced few mature seeds (data not shown). Flowering started at 52 days for earlier lines and lasted until 80 days from planting for the later flowering lines. Early flowering echium populations have higher seed yields. Seed yield and oil content was highest for line 104 in 2006 (Table 5). Line 104 can become a good parent line for future crosses for high seed yield and oil content. Highest GLA and SDA content was 11.9 and 13.5%, respectively, for those populations producing sufficient seed for analysis. No significant differences among populations were found for GLA and SDA.

Echium invasiveness risk is low in North Dakota. No volunteer plants were observed from shattered seed the following season.

CONCLUSIONS

Results indicate echium has a low invasiveness risk, and good production potential, according to seed yield (max. 425 kg ha^{-1}), seed oil content (max. 298 g kg^{-1}), GLA (max. 11.9%), and SA (max. 15.2 %) obtained for eastern North Dakota. The crop can be produced with conventional equipment for planting and harvesting making echium a potential alternative for the region. Genetic diversity identified among the wild Chilean echium populations, although not very high, is a valuable source for development of improved commercial echium cultivars with better agronomic characteristics, higher seed yield, seed oil content, and GLA and SDA contents.

Table 5. Mean days to flowering, plant height, seed yield, seed oil content, and fatty acid composition of selected Chilean echium lines grown at Prosper, North Dakota[z], ranked by seed yield.

Line	Days to flowering	Plant height (cm)	Seed yield (kg ha^{-1})	Oil content (g kg^{-1})	Fatty acid content (%)					
					Palmitic	Oleic	Linoleic	GLA[y]	ALA	SDA
104	52	74	284	294	8.2	17.8	16.4	9.9	30.7	11.9
119	80	75	143	244	7.3	17.6	15.7	9.8	32.8	12.6
114	80	75	109	274	7.7	17.7	21.5	11.9	27.8	9.0
103	52	74	58	258	7.1	16.6	15.5	9.5	34.7	12.1
116	50	76	58	265	7.3	14.9	15.7	8.8	36.4	12.3
117	52	76	29	244	7.4	16.6	14.8	8.7	34.6	13.5
109	80	74	17	197	7.4	17.3	16.1	9.5	33.0	12.4
126	80	74	10	154	7.3	18.8	15.7	9.4	31.8	12.4
107	77	77	4	163	6.8	15.1	14.7	9.5	36.6	12.9

[z]Data for fatty acid composition were done with seeds from 2005. Days to flowering, seed yield, and oil content are from 2006.

[y]GLA= Gamma-linolenic acid, ALA= alpha-linolenic acid, SDA=stearidonic acid.

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