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Borage: A New Crop for Southern Chile

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Borage (*Borago officinalis* L., Boraginaceae) is an herbaceous annual (Janick et al. 1989). Current interest in this crop is for its seed which contains a high percentage of gamma-linolenic acid (GLA) (all- cis 6,9,12-octadecatrienoic acid) in the oil. GLA is a precursor of the prostaglandin PGE1 in the human body (Willis 1981) which is vital in many body functions, such as antithrombotic inhibitory effects on aggregation of platelets, lowering blood pressure, and inhibiting cholesterol formation (Belisle 1990). Potential medical uses of GLA include treating atopic eczema to decrease disease symptoms (Wright and Burton 1982) and reducing side effects of diabetes, such as vascular damage, altered platelet function, and arteriosclerosis (Kies 1989).

Commercial seed sources of GLA include evening primrose and some *Ribes* species. Oil content of borage seeds averages between 300 and 380 g kg^{-1} of which 20% to 23% is GLA. Oil and GLA content are higher in borage seed compared to those from evening primrose (*Oenothera biennis*) and *Ribes* spp. (Kleiman et al. 1964; Wolf et al. 1983).

Main producers of borage seed are Canada, England, New Zealand (Nicholls 1996), The Netherlands, and the United States. US borage production was highest in North Dakota in 1999. The market for borage oil, as for evening primrose oil, fluctuates wildly with some years of over-supply and others of low production. The major reason for this is that the major borage producer is Canada, where growers can produce seed at the lowest cost, but where there is a high risk for crop failure due to early frosts. Therefore borage seed volume marketed each year is variable, fluctuating between 500 and 2000 tonnes. Seed prices fluctuate between US$2.5–4/kg depending on supply and seed quality. Seeds with higher than 24% GLA are easier to sell during years of oversupply.

Borage is grown usually at higher latitudes to increase GLA content. Most processing companies require a minimum 22% GLA which is not easy to obtain at latitudes lower than 38°. Southern Chile has climatic and soil conditions favorable for borage seed production. Southern Chile's climate is very similar to that of New Zealand which is the second largest borage producer. Therefore borage has been one of the alternative crops evaluated in South Chile. Several agronomic trials such as seeding dates, base temperature determination, harvest dates, plant density, and adaptation to locations have been designed to determine borage adaptability to Southern Chile.

BORAGE RESEARCH IN CHILE

Borage research was initiated by the plant Production Department of the University of Concepción, Chile in 1996. Previous research in Central Chile had indicated that borage production was not feasible because GLA content was lower than the 22% which is required by processors. In an effort to search for new alternative crops for producers of Southern Chile, and the interest of Canadian and British Companies to establish borage seed production in Chile, first trials were conducted at the Experimental Station of the University of Concepción located in Chillán (36° 26" S, 72° 06" W). Several trials such as, seeding dates, harvest dates, base temperature determination, plant density, and GLA content at different locations were conducted in 2001.

LONCOPAN S.A., a processing plant located in Santiago, Chile, helped finance the research in Southern Chile. In 2001 there were 75 ha of commercial borage production.

Determination of Optimum Harvest Stages

To determine seed maturation and abscission stages the code described by Simpson (1993a) was used where 1–4 are vegetative and 5 and its divisions indicate how flowering advances. Borage seed was harvested at six different dates from Dec. 29 to Feb. 2 in Chillán in 1997. Seeding date was Aug. 26. The soil is a Medial Typic Melanoxerand. No fertilization was added. The crop was irrigated by flood irrigation. Weeding was by hand. Seeding rate was 2.3 kg/ha. Experimental design was a randomized complete block design with four replicates.

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Seed yield increased with seed maturity stage. The highest seed yield was reached at stage 5, when the average flower position on the main stem with mature seed was 13.4 in sequence, designated "5(13.4)" (Fig. 1). Yield at this stage, however, was not significantly different from stage 5(8.5) or 5(18.1). Thus, growers are advised to harvest between these three stages. Nevertheless, US growers recommend a harvest stage from 5(1.0) through 5(4.0), in order to harvest the first matured seeds Simpson (1993b). The first flowers of the main stem usually have four seeds and they also have a higher seed weight than those that mature later.

Potential seed yield, defined as harvested seed plus shattered seeds, was 474 kg/ha at the latest harvest date (Fig. 1). Seed yield in this first experiment was low probably because the field was not fertilized with nitrogen and leaves showed signs of nitrogen deficiency. Nitrogen fertilization was not used because soil levels indicated it was unnecessary. Also, a period of water stress close to flowering initiation probably reduced seed yield potential.

Oil content and composition are shown in Table 1. GLA (γ18:3) content did not reached the expected 22% required by processors, probably because this location is too hot during seed development. More details about these research results are published in Berti et al. (1998).

Determination of Optimum Seeding Date in Chillán

The objective of this trial was to determine if an earlier seeding date allowed seed development to occur with lower temperatures and therefore increase GLA content. Borage was planted on four different dates (July 8, Sept. 16, Sept. 30, and Oct. 15). First date, which is in the middle of the mild winter in Chillán, was eliminated from the analysis. This study was conducted in Chillán during the 1999–2000 season. The soil is a Medial Typic Melanoxerand. Nitrogen was added when plants had 5 to 7 true leaves. Fertilization rate was 100 kg N/ha as urea. Crop was irrigated by flood irrigation. Weeding was by hand; seeding rate was 5 kg/ha. A randomized complete block design with four replicates was used.

Plants were harvested at the 5(5.0) stage according to Simpson (1993a). Seed yield and potential seed yield increased with later seeding dates (Fig. 2). GLA also increased with later seeding dates (Table 2), con-

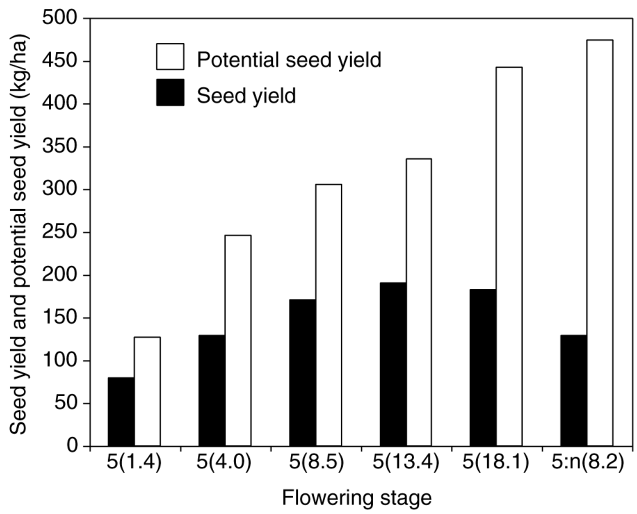

Fig. 1. Borage seed yield and seed yield potential as maturity and abscission stages advance. Number in parenthesis is the position of the last flower on the main stem that had a mature seed. Stage 5:n(8.2) means that all flowers on the main stem are mature and 8.2 flowers on the lateral stem are mature

Table 1. Borage seed oil content and composition in different maturity stages. Source: Berti et al. 1998.

Maturity stage	Oil content (%)	Fatty acid[z] distribution (% of total)						
		16:0	18:0	18:1	18:2	γ18:3	20:1	22:1
5(1.4)	33.1	11.26	4.52	19.57	36.12	18.46	4.22	2.70
5(4.0)	32.7	11.43	4.83	20.49	35.80	17.49	4.18	2.68
5(8.5)	31.5	12.03	4.39	20.28	35.37	17.71	4.18	2.84
5(13.4)	32.1	11.75	4.61	20.95	35.29	17.30	4.18	2.80
5(18.1)	31.7	11.88	4.56	20.05	35.38	17.78	4.19	2.95
5n(8.25)	31.9	11.76	4.59	20.61	35.10	17.61	4.19	2.95

[z]16:0=palmitic acid, 18:0=stearic acid, 18:1=oleic acid, 18:2=linoleic acid, γ18:3=gamma–linolenic acid, 20:1=arachidoleic, 22:1=erucic acid.

trary to what was expected due to seed maturity. Samples from earlier seeding dates had more immature seeds. Seed at different stages of maturity; light brown (immature), brown (semi-mature), and black (mature) were analyzed for GLA content and immature seed had the lowest GLA content (Table 3).

Base Temperature for Germination

Data from the seeding date trial was used to determine base temperature. Days from seeding to 50% emergence and from 50% emergence to 50% flowering (f) were calculated. The rate of flowering 1/f was related to daily temperature during the measuring period. Thus, $1/f=a+bT_b$, where the base temperature (T_b) is the intercept with the x axis.

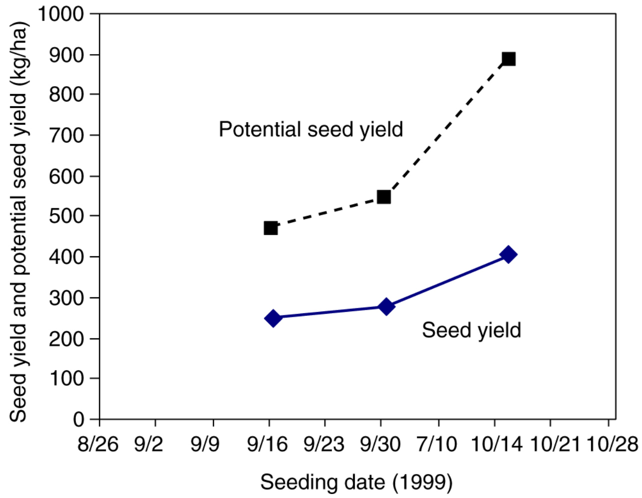

Fig. 2. Seed yield and seed yield potential in borage sown at different dates.

Table 2. Borage fatty acid composition and its variation with different seeding dates in 1999.

	Fatty acid[z] distribution (%)				
Seed date	16:0	18:0	18:1	18:2	γ18:3
July 8	11.7	2.7	20.4	37.5	22.2
Sept. 16	11.9	1.7	21.2	31.3	25.8
Sept. 30	13.6	2.4	19.6	30.7	25.8
Oct. 15	13.6	0.4	22.3	34.1	29.1

[z]16:0=palmitic acid, 18:0=stearic acid, 18:1=oleic acid, 18:2=linoleic acid, γ18:3=gamma–linolenic acid.

Table 3. Influence of seed maturity on fatty acid composition of borage seed oil.

	Fatty acid[z] distribution (%)				
Seed maturity	16:0	18:0	18:1	18:2	γ18:3
Immature (light brown)	12.8	6.2	21.3	32.5	14.3
Semi mature (brown)	12.0	4.6	19.1	35.2	19.0
Mature (black)	13.3	4.2	18.4	38.8	21.0

[z]16:0=palmitic acid, 18:0=stearic acid, 18:1=oleic acid, 18:2=linoleic acid, γ18:3=gamma–linolenic acid.

The base temperature (T_b) for flowering was 6.2°C (Fig. 3). This temperature indicates why earlier seeding did not have higher seed yield. Plants are able to grow below 6.2°C but they do not flower until the temperature is higher. Also, in Southern Chile, fall or winter plantings are at high risk of root damage from frost. Volcanic ash derived soils present in Southern Chile increase in volume when they freeze, cutting roots.

Plant Density Study

The optimum planting density required to maximize seed yield is not yet clear. A study was conducted in Chillán during the 2000–2001 season to determine the optimal plant density to recommend to Chilean growers. The soil is a Medial Typic Melanoxerand. Phosphorus fertilizer was incorporated into the soil at a rate of 80 kg/ha before seeding. Nitrogen was added when plants had 5 to 7 true leaves. Fertilization rate was 120 kg N/ha as urea. Crop was irrigated by flood irrigation. Weeding was done by hand; seeding rate was 7 kg/ha. A randomized complete block with a split-plot arrangement was used. The main plot had between row distances (40 and 60 cm) and the subplots had six plant densities (20,000, 40,000, 80,000, 110,000, 150,000, and 185,000 plants/ha). Seed yield exhibited a quadratic response to plant density. Maximum yield was obtained with 172,222 plants/ha at 60 cm between rows and 205,000 plants/ha at 40 cm between rows (Fig. 4). These results are similar to those recommended for producers in North Dakota, but much higher than those published earlier by Beaubaire and Simon (1990).

Seed shattering remains the main problem in borage production. The highest shattering was observed at the lowest plant densities, which was expected because these were subjected to more movement by wind.

Seed Yield and GLA Content at Different Locations in Southern Chile

Seed yield has been recorded in Chillán during three seasons (Table 4). The lowest yield were observed during 1997–1998 probably because the crop had a nitrogen deficiency. The 1999–2000 trials were fertilized with nitrogen, increasing the seed yield to 400 kg/ha. During the last season 2000–2001 seed yield reached 431 kg/ha.

GLA content was analyzed for the 1997, 1999, and 2001 seasons. Lowest GLA content was always observed at Chillán, which is a warmer location and may explain the lower values. After several years of study in Chillán, it is clear that best gamma linolenic acid content is produced below 40° south.

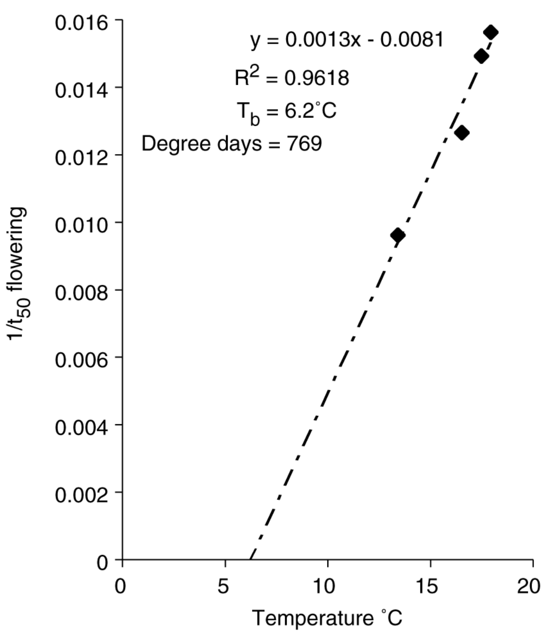

Fig. 3. Determination of base temperature (T_b) for flowering in borage.

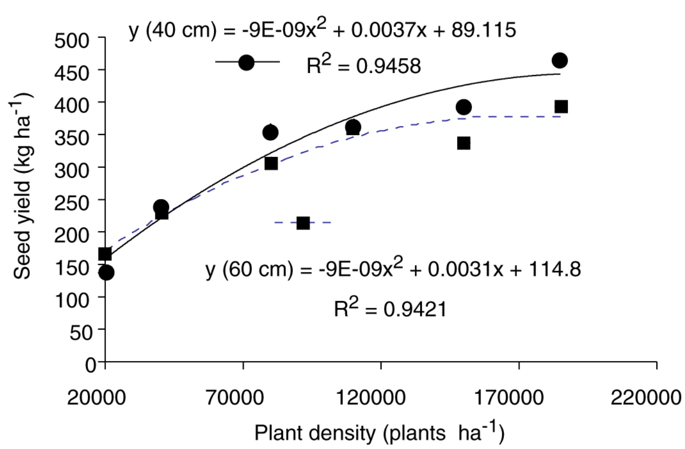

Fig. 4. Response of seed yield to plant density at 40 and 60 cm between rows.

Table 4. Seed yield, oil content, and fatty acid composition at different location and year in Southern Chile.

Location/Year	Latitude	Seed yield (kg/ha)	Oil content (%)	Fatty acid[z] composition (%) 16:0	18:0	18:1	18:2	γ18:3	22:1	22:6
Chillán, 1997	36º 26" S	189.9	33.1	11.26	4.52	19.57	36.12	18.46	2.70	--
Chillán, 1999	36º 26" S	402.3	--	11.7	2.70	20.4	37.5	22.20	--	--
Chillán, 2001	36º 26" S	431.1	--	--	--	--	--	--	--	--
Mafil, 2000	39º 85" S	352.9	32.4	10.00	4.40	17.50	37.00	21.50	3.00	2.00
Puyehue, 2001	40º 38" S	88.3	31.2	10.20	3.20	15.40	38.90	24.90	2.90	1.00
P. Varas, 2001	41º 05" S	349.4	31.0	10.10	2.70	13.50	38.20	26.90	2.70	1.70
I. Quihua, 2001	41º 83" S	66.4	32.0	9.30	3.40	15.20	38.60	24.80	2.70	1.70

[z]16:0=palmitic acid, 18:0=stearic acid, 18:1=oleic acid, 18:2=linoleic acid, γ18:3=gamma-linolenic acid, 22:1=erucic acid, 22:6=docosahexaenoic.

CONCLUSIONS

Borage can be produced in Southern Chile. Seed yields fluctuated between 300 and 400 kg/ha and above 22% GLA. Borage should be sown early in the spring from Sept. through Oct. A base temperature of 6.2°C is required for flowering. Planting density should be between 172,222 and 205,000 plants/ha to obtain maximum seed yield.

Seed should be harvested at maturity stages between the 5(8)and 5(13.4), although US growers recommend an earlier stage, approximately 5(1) to 5(4), Simpson (1993b). Immature seed has a lower percent of GLA of approximately 14%.

Chilean growers can produce borage at a cost of approximately US$500/ha, a net income of US$300/ha. However, there is a high risk for crop failure because early rainfall at harvest time may prevent harvest.

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