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Seed yield, oil content and fatty acid composition of three botanical sources of ω-3 fatty acid planted in the Yungas ecosystem of tropical Argentina

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Abstract *Studies have shown that the fatty acid composition of oils consumed can affect the risk of cardiovascular heart disease, and many consumers are therefore looking for sources of ω-3 fatty acids. Three herbs of the family Lamiaceae, chia (*Salvia hispanica *L.), golden chia (*Salvia columbariae *Benth.) and winter savory (*Satureja montana *L.), all of which produce seeds rich in ω-3 fatty acid, were planted in northwestern Argentina to determine their production potential in terms of seed yield, oil content and fatty acid composition. Chia seed had the highest oil content (29.9%), followed by golden chia (21.0%) and winter savory (8.0%). All three crops exhibited similar fatty acid profiles, with α-linolenic ω-3 fatty acid being the largest component. Golden chia had the highest α-linolenic fatty acid content: 17% and 11% more than chia and winter savory, respectively. Golden chia's shattering, however, is a major disadvantage for commercial production, making this the least attractive crop of the three. Copyright © 2008 John Wiley & Sons, Ltd*

Key words: chia, *Salvia hispanica*, *Salvia columbariae*, *Satureja montana*, omega-3, fatty acid, oil content

Introduction

Studies have shown that the fatty acid composition of dietary oils can increase or decrease the risk of suffering cardiovascular heart disease. This is very likely to affect the consumption and price of oilseed crops in the future. Argentina is one of the main oilseed producers and exporters in the world, hence changes in oilseed demand will affect Argentina's economy, since 24% of its exports are vegetable oil (CIARA 2006).

The principal edible oils produced in Argentina come from soybeans, sunflower and corn (maize). All three oils are high in ω-6 and low in ω-3 fatty acids. A number of epidemiological and controlled medical studies have demonstrated that an imbalance in one's dietary ω-6 : ω-3 fatty acid ratio is an independent risk factor associated with cardiovascular heart disease (Simopoulos 2003). As a consequence, many health-conscious consumers are looking for readily available sources of ω-3 fatty acids.

Although the largest part of Argentina's oilseed production comes from the temperate central region of the country, oilseed crops are becoming more important for the economic development of other areas, such as the northwest. Presently, the largest oilseed crop in the tropical and subtropical regions of northwestern Argentina is soybeans. It is important not only in terms of production, but also because of the oil extraction facilities operating in the region. Thus any changes in world soybean demand or price will significantly affect the economy of the region. If a new oilseed crop – especially one that has a healthy fatty acid profile and is adapted to the region – could be found, it would be an attractive alternative for growers.

Three herbs of the family Lamiaceae, chia (*Salvia hispanica* L.), golden chia (*Salvia columbariae* Benth.) and winter savory (*Satureja montana* L.), produce seeds that are rich in ω-3 fatty acid. To assess their production potential in northwestern Argentina a trial was undertaken to determine their seed yield, oil content and fatty acid composition.

Materials and methods

The experimental plot was established on the Anta-Muerta farm, Oran, Salta, Argentina (22°53′S 64°24′W, 406 m above sea level). This farm is located in the Tucuman/Bolivian Forest in what is known as the Yungas ecosystem. The soil type according to the FAO classification system is luvic Phaeozem. The plot was laid out in a randomised design with three replications of each of the three herb species (chia, golden chia, winter savory). Each replicate was composed of three rows 10 m long, spaced 1 m apart. The seeds of winter savory, golden chia and chia were supplied by The Omega Tree (Chandler, Arizona), the University of Arizona and Corporación Internacional de Comercio y Servicios S.A. (Buenos Aires, Argentina), respectively.

The seeds were sown on 18 May 2004. Furrow irrigation was applied three times to supplement rainfall: once per month from June to August. The sub-plots were harvested in their entirety on 1, 5 and 15 October for chia, winter savory and golden chia, respectively. After harvesting by hand (and noting evidence of shattering), the seeds were cleaned and weighed. Precipitation and temperature (maximum, minimum and mean) were recorded over the experimental period (Table 1).

Oil contents were determined by the Soxhlet method, and expressed as a percentage of the cleaned seed weight and as equivalent oil yield by weight. Fatty acid composition was determined using a Perkin-Elmer 300 gas-liquid chromatograph with a Unisole 3000-Unipor C80/100 column following ISO methods 5508/1990 and 5509/1978. For these analyses, 200 g sub-samples were taken from the combined harvest of each sub-plot, then subdivided for oil and fatty acid analyses.

Seed yields were subjected to analysis of variance. When the F-value was significant, means were separated using Duncan's New Multiple Range Test. Standard deviations were determined for oil content and fatty acid percentages.

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Table 1. Weather conditions at the farm site during the experiment

Period (dates)	Temperature (°C)					Rainfall (mm)
	Maximum		Minimum		Mean	
	extreme	mean	extreme	mean		
18 May–31 May	23.0	19.4	3.3	8.3	13.6	10
01 Jun–30 Jun	27.0	21.5	0.2	10.5	15.7	6
01 Jul–31 Jul	31.2	22.8	1.5	10.3	16.1	2
01 Aug–31 Aug	36.6	25.2	4.5	11.4	17.9	6
01 Sep–30 Sep	40.0	32.4	2.4	15.9	22.2	76
01 Oct–15 Oct	40.0	37.7	13.1	20.4	25.4	0

Table 2. Seed yield, oil content (based on weight of cleaned seed), growth period and shattering characteristics of the three herb species, with standard deviations (SD)

Species	Seed yield[1]	Oil content		Growth period (days)	Shattering observed
	($kg\ ha^{-1}$)	(%)	($kg\ ha^{-1}$)		
Winter savory	220[b]	8.0	17.6	140	No
Chia	2253[a]	29.9	673.7	135	No
Golden chia	133[b]	21.0	27.9	150	Yes
SD	—	10.7	375.9	7.6	—

[1]Mean seed yields followed by the same letter are not significantly different at $p < 0.05$, according to Duncan's New Multiple Range Test.

Results and discussion

The seed yield, oil content, growth period and shattering characteristics of the three species are listed in Table 2. Chia had the highest seed yield, which was significantly ($p < 0.05$) greater than the other two crops. The dramatic yield difference between chia and the others could be related to the way in which the three species are commonly used. Although all three are used in human diets, winter savory is cultivated for its leaves and used as a culinary herb, whereas the seeds of chia and golden chia are used as food. The difference between the latter two plants is that domestication of chia began at least 2000 years ago (Ayerza and Coates 2005), while golden chia remains undomesticated. It should be noted that, although golden chia seeds have been consumed by a number of native nations in the southwestern USA and northwestern Mexico for many years, the seeds are collected from wild populations (Adams et al. 2005). Lack of domestication of golden chia is supported by the high shattering which was observed in this trial as evidenced at harvesting by the number of open seedless capsules and seeds on the ground. Shattering was stated by Cahill (2004) to be an unequivocal sign of the wild stage of this species.

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Chia seed yields found herein were higher than the 1266, 2031 and 2120 kg ha^{-1} reported for experimental plots sown in Argentina, Venezuela and Columbia, respectively, during the 1990s (Ayerza 1995). However, since the genotype tested herein was different from that of the earlier experiments, the variation in seed yields could be related to a genetic × environment interaction, to genetics, or to environment alone.

Chia yielded the highest oil content (29.9%), followed by golden chia (21.0%), and winter savory (8.0%) (Table 2). The chia oil content in this trial was within the 28.5–32.7% range reported by Ayerza and Coates (2004) for chia commercially produced in nine areas of Argentina, Bolivia, Columbia and Peru. The golden chia and winter savory oil contents reported herein were lower and higher, respectively, than the oil contents of 32% and 5.7% reported by Ucciani (1995) for these crops.

In general, all three crops exhibited similar fatty acid profiles, with α-linolenic ω-3 fatty acid being the largest component (Table 3). Golden chia had the highest ω-3 content, containing 17% and 11% more α-linolenic fatty acid than chia and winter savory, respectively.

The palmitic and α-linolenic fatty acid contents of chia were among the highest and lowest values, respectively, that have been reported (Ayerza and Coates 2004; Coates and Ayerza 1996, 1998). These extreme values could be related to the high mean maximum temperature recorded during seed formation. Ayerza (1995) reported significant ($p < 0.05$) correlations between mean maximum temperature and fatty acid content in chia: a negative (–0.88) correlation with α-linolenic fatty acid and a positive correlation (+0.87) with palmitic fatty acid. He compared chia seed produced at mean maximum temperatures of 23.4, 23.6, 25.2, 27.0 and 28.6°C and reported significantly ($p < 0.05$) lower and higher contents of α-linolenic and palmitic fatty acids, respectively, in seeds produced at the two highest temperatures. These temperatures, however, were lower than those measured during seed production in the

Table 3. Fatty acid composition (as percentage of total fatty acids) of the three herb species and ratio of ω-6 to ω-3 fatty acids with standard deviations (SD)

Fatty acid	Specified fatty acid as % of total fatty acids			SD
	Winter savory	Chia	Golden chia	
16:0 palmitic	5.1	8.9	5.1	2.69
16:1 palmitoleic	—	—	0.2	—
18:0 stearic	1.8	3.2	2.1	0.74
18:1 oleic	7.8	10.0	10.6	1.47
18:2 linoleic (ω-6)	26.4	22.6	16.7	4.89
18:3 α-linolenic (ω-3)	57.5	54.8	64.0	4.73
20:0 arachidic	0.3	—	0.1	0.14
20:1 gondoic	—	—	0.2	—
22:1 cetoleic	—	—	0.2	—
24:0 lignoceric	0.2	—	—	—
ω-6 : ω-3 ratio	0.46	0.41	0.26	0.10

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Anta-Muerta experiment (Table 1). The α-linolenic fatty acid contents of golden chia and winter savory were lower than those typically reported for these two species (Ucciani 1995), supporting the generally accepted principle that high temperatures affect oil composition during seed formation.

From the standpoint of a favourable ω-6 : ω-3 ratio, golden chia seed proved superior to the other crops, because of the comparatively high α-linolenic fatty acid and low linoleic fatty acid contents.

Data from this trial indicate that all three species can grow and produce seeds in northwestern Argentina. Although golden chia contained the highest α-linolenic content, 17% more than chia, this did not compensate for the 17-fold greater seed yield of chia. The shattering exhibited by golden chia is a major disadvantage from a commercial point of view. However, its high α-linolenic content, combined with its arid plant characteristics (low water requirements), might justify a domestication programme.

In the case of chia, additional studies are needed to determine its potential as a new crop for the Yungas ecosystem of northwestern Argentina. Such studies would need to evaluate the potential interactions of genotype × environment on α-linolenic fatty acid content, and assess a number of other factors such as water requirements, crop cycle, etc.

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