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Communication

The Chia (*Salvia hispanica* L.) – the rediscovered Meso-American functional food crop.

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Abstract: Among the plant resources in pre-Columbian Mexico and Central America, the Chia (*Salvia hispanica* L.) is unique in being the only member of the Lamiaceae cultivated for the mericarps. Recently the crop has gained considerable attention due to its high of content omega-3 polyunsaturated fatty acid, antioxidants, fibre and protein classifying it as a nutraceutical.

Currently, the global production yield ranges between approx. 600 to 1,200 kg ha^{-1}; in comparison yield results from a field experiment using a local landrace and an improved cultivar ranged between 1,336 to 1,706 kg ha^{-1}, respectively. In Guatemala retail market prices range from € (2.1-)2.6(-3.0) kg^{-1} compared to a price range of organic chia in Danish supermarket and health food retailers of € (7.5-)10.1(-23.8) kg^{-1} depending on the country of origin. The global demand, estimated at 40,000 tons annually, has resulted an increased interest in this profitable product in many tropical countries.

Keywords: Chia; *Salvia hispanica*; nutraceutical; pre-Columbian crop;

1. Introduction

Chia (*Salvia hispanica* L.) is part of a group of plants used by pre-Columbian cultures in Mexico and Central America, from where it is believed to originate [1–3]. According to old clerical records, the chia was known to and used by ancient pre-Columbian cultures, e.g. the Aztecs, and it was even used as currency [1,4]. For many years, it was an important part of the diet of indigenous cultures in Mexicans and Central America and in recent years, it has drawn attention as a source of omega-3 polyunsaturated fatty acid and as a source of antioxidants, fibre and protein [1,3,5]. Its biochemical properties have made both producers of nutritious food as well as pharmaceutical companies interested in it. Currently, there is a global trend to improve the diet and nutritious and healthy foods are promoted to assist in improving people's life-quality. The need for this diet change is due to both the rhythm of modern life that has made us more sedentary and increased the preference for processed and fast foods. This modern life-style has led to an increase in the incidence of cardiovascular diseases, cancers and diabetes, which are the main causes of premature deaths today. To remedy the life-style associated poor health led to the search for alternative sources of food that are not only nutritious, but also healthy and help reduce the risk of these diseases [6–8].

The production yield ranges between approx. 600 to 1,200 kg ha^{-1}; however, the demand is growing due to the properties of this plant making it a potential source of income for the communities located in Mexico and Central America, although it is known that the crops is

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produced in several other countries. It is estimated that the present annual global demand is approx. 40,000 tons, and it predicted that this demand would increase [9–12].

1.1. Botanical description

Chia (*Salvia hispanica* L.) is part of the Lamiaceae family, where there are other plants such as Mint (*Mentha* L. sp.), Rosemary (*Rosmarinus officinalis* L. syn. *Salvia rosmarinus* Schleid.) and Oregano (*Origanum vulgare* L.). They are annual herbs up to 1.75 m, robust, erect, sparsely branched, often with a woody base; green stems, sometimes with some purple pigmentation. Leaves petiolate, ovate or lanceolate, membranous, the upper surface green, the margins serrated, the apex acuminate; Inflorescences 4–10 cm, terminal, in dense racemes; fruiting calyx acrid, markedly urceolate and persistent. Corolla 8–9 mm, blue or purple; two stamens with exerted anthers; exerted style, gynoecium superior, bicarpellate, fruit schizocarpic with four nutlets/mericarps.

Nutlets/mericarps approx. 1.75 × 1.2 mm, flattened, grey-brownish, with dark brown mottling and testa prominently hydrophilic. In the wild state, it flowers and fructifies from May to October and can be found in the forests of tree genera like *Ulmus* L., *Pinus* L., *Quercus* L. and in open grasslands; as well as in bean and maize fields, or cultivated [13–16].

1.2. Origin and distribution

Chia is an annual species native to Central America, the mountainous areas of western and central Mexico, as well as Guatemala. As mentioned above, it is found naturally in areas of oak or pine-oak forests and is distributed in semi-warm and temperate environments of the Transversal Neovolcanic Axis of the Western Mother Sierras and southern Chiapas, at altitudes that range between 1,400 and 2,200 m a.s.l. [2–3].

1.3. History

Historically, chia nutlets were the main food of the Nahuatl (Aztec) culture of central Mexico. The Jesuit chroniclers considered the chia as the third most important crop of the Aztecs, after maize (*Zea mays* L.) and beans (*Phaseolus* sp.), and before amaranth (*Amaranthus cruentus* L. and *A. hypochondriacus* L.). Tributes and taxes to the Aztec clergy and nobility were frequently paid in chia nutlet [4,17,18]. In pre-Columbian times, chia was a very important crop for the civilizations of that time, it was cultivated in great quantity by the Aztecs, including the nutlets in their diet, in medicine, art and even as offerings in pagan religious rituals; it also functioned as currency and as a tax to the peoples subjected by this empire.

The Mayan culture called it chihaan, which means strong or fortress [14]. Since then it has remained as part of the culinary culture of the ethnic groups of the region. One popular way was through chia fresco, which following the introduction of the citrus fruits is generally an orange or a lemon soda to which chia nutlets are added. In recent years, due to its properties as a superfood, being a source of Omega-3, antioxidants and fibre for human nutrition, it has been in great demand. As a result, ‘La Chia’ has become established as a pseudo-cereal and an emerging crop in different parts of the world [4,6,19–23].

1.4. Uses

The most common way to use Chia is by soaking the nutlets in water, they form a mucilaginous-gelatinous mass used as a flavouring in fruit juices and is consumed as a refreshing drink. The gelatinous mass of the nutlets can also be prepared as a pudding. The germinated

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seedlings are frequently eaten in salads, sandwiches, soups, and stews. Due to their mucilaginous properties, they are commonly seeded on clay or other porous materials, which is kept moist. From the ground nutlets, a flour is obtained that can be used to make bread, stews and cakes, generally mixed with cereal flours, and it is a very good source of easily digestible proteins and fats. Some other uses were for combatants who went to war as a revitalizer and for women preparing for childbirth [24–27].

2. Chia cultivation

2.1. Agronomic aspects

Mistakenly, the so-called 'seeds' of the Chia are in fact schizocarpic fruits or nutlets, morphologically termed mericarps, 1–1.2 mm wide and 2–2.2 mm long, they present different shades of colours varying from black to white passing through grey, with irregular and reddened spots. When soaked in water, the nutlets, as mentioned, give rise to a gelatinous liquid due to the presence of mucilage on their surface. The gelatinous liquid is the main product of this plant, although both leaves and stems are known to be edible [3,13].

2.2. Genetic diversity

The region of Mexico and Guatemala is a centre of origin and diversity for important crops such as both maize and beans and emerging crops for oil production such as *Jatropha curcas* L. [28]. Furthermore, this region is considered the centre of diversity and origin of this species and is where the Chia began to be domesticated as a crop by the Aztec and Mayan cultures; much later, the crop has been exported for production to other countries. Studies of the genetic diversity in southern Mexico and Guatemala have shown high variability in wild materials and its reduction in cultivated ones, which is to be expected because of the domestication process. However, the high genetic variation presented in wild populations presents a potential to continue with improvement programs for this species, which has a high potential as a superfood, as it is a rich source of Omega-3 [18,29–31].

There are a few registered varieties, these are the ones that contain high levels of omega-3, however, this content is related to the climatic conditions where it is grown). In the regions of Mexico and Central America, they recommend using the nutlets found in the region, because they will develop better as they are native. The nutlets that are exported for production in other countries is classified by the colours of the nutlets and the flower colour [12,32,33].

2.3. Soil

Chia grows well in both sandy loam soils as well as those of moderate fertility. Of course, it grows best in those of good fertility. Regarding the humidity level, Chia is also tolerant to drought, not needing much precipitation for its growth and subsequent development, but the soils must be well drained. The proper pH for growing is 6.5–7.5. The rains do not affect it either, but if an intense rain occurs at the time of flowering it can reduce the fruit set by damaging the flowers [12,17,34,35].

2.4. Land preparation

This operation can be done in a conventional way with a plough and harrow; or with a minimum tillage approach for direct sowing, which is the most recommended as it contributes to soil conservation [12,17,21,35].

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2.5. Planting method

Direct sowing to the Chorrío: Open small furrows and deposit the nutlets superficially, the nutlets have a size of 2–3 mm; 20–25 nutlets should be distributed per meter in a linear row with a distance of 60 cm between rows [12,17,34,35].

2.6. Seeding time

In Nicaragua, from the end of August to September, inclusive until October.

2.7. Crop cycle

It is an annual crop, with a vegetative cycle of 90–150 days; they are short day photoperiodic plants. The size of the plants on average has a height that varies from 1.00 to 1.70 m. In its region of origin, Mexico and Central America, sowing takes place in mid-May or June [12,17,34,35].

2.8. Seeding depth

The Chia requires a shallow planting depth to emerge successfully, just enough to cover the nutlets and a maximum of 10 mm. The nutlets requires moisture to germinate. In many commercial plots, sowing in furrows 0.7–0.8 m apart with a sowing density of 6 kg of nutlets per hectare. The most appropriate density is the one greater than 40,000 plants ha^{-1} [12,17,34,35].

2.9. Fertilization

According to field observations, it has been determined that the crop expresses good growth in soils that present large fluctuations in their nutrients, mainly phosphorus and potassium; however, a low nitrogen content can be a limiting factor to obtain good grain yields. Note, it is recommended to avoid the application of chlorinated fertilizers [3].

2.10. Climatic conditions

The minimum and maximum growth temperatures of this species are 11 °C and 36 °C, respectively, presenting an optimal range between 16 and 26 °C [5,36]. The species does not tolerate frost, since it grows naturally in tropical and subtropical environments. Although high levels of soil moisture are desirable for germination, once established the plant does not present growth problems in water-limiting conditions [12,17,34,35].

It is characterized by being a plant with a short day photoperiod, so its growth and fruiting period depends on the latitude where it is established, requiring that the duration of sunlight falls below a threshold of the order of 12 hours. That is why the sowing date is a relevant element, since it determines the duration of the vegetative growth period, when flowering occurs at a fixed time, determined by the length of the day [16]. In this way, very late sowing dates, with photoperiods close to the flowering induction threshold, could have an effect on a too short growth period, which would affect a lower production. On the other hand, too early sowing dates, i.e. with a longer day length, cause vegetative growth that extends over time, generating tall plants, with a low harvest index (HI), low yields and possible problems of tendency to scatter at harvest [12,16,17,34,35,37].

2.11. Crop husbandry

In Mexico and Central America, the cultivation of Chia can be done in association with other crops such as maize and beans or as a monoculture. It is worth mentioning that the

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association of this crop with beans and maize gives the farmer an alternative, in order to obtain income, if the beans or maize, or both, had problems. Currently with the climatic changes the production of maize and beans, we have problems due to the droughts proven by natural phenomena such as El Niño, or floods with La Niña, which are more frequent. This makes the cultivation of Chia in association a lifesaver for farmers.

3. Field experiment

A propagation and experimental planting program of chia (*S. hispánica*), was conducted during March 2013 to January 2014 to evaluate differences between improved/selected and native materials, and establish a seed bank for distribution in home gardens.

3.1. Materials and methods

The field study conducted at the Faculty of Agronomy of the University of San Carlos de Guatemala (FAUSAC) *centro experimental docentea agronomia*, located near the university campus in Guatemala City at 14°34'53.1"N 90°33'18.1"W.

The two seed materials used were a. 18 g 'Improved Material' supplied by Armando Cáceres, improved through selection of desirable traits; and b. 500 g 'Native Landrace' obtained at the local wholesale market 'Central de Mayoreo' in Guatemala City.

Land preparation – the planting area was 18 × 4 m, located in the shady area of the collection of medicinal plants, where the first step was to extract the Napier grass (*Pennisetum purpureum* Schumach.) rhizomes that were in that area. This weed had invaded the area and the rhizomes it produces complicate its control.

A total of 30 rows, 6 m long and a distance of 0.8 m between rows were made (Fig. 1a–d).

3.2. Results

All results are average data, based on seven samples per m^2 for each of the two materials tested; harvests of the Improved Material took place in October 2013 and of the Native Landrace in January 2014 (Table 1.).

Table 1. Trial design and yeild of field study.

Field study	Improved Material	Native Landrace
Plot size	57.6 m^2	86.4 m^2
No. rows	18	12
Length of row	6 m	6 m
No. plants row^{-1}	24	24
Inflorescences $plant^{-1}$	136	104
Nutlets $calyx^{-1}$	3	3
Nutlets g^{-1}	1108	1280
Nutlets g $plant^{-1}$	34.03	26.72
Nutlets g row^{-1}	816.72	641.28
Nutlets g m^{-2}	170.2	133.6
Nutlets t ha^{-1}	1.7	1.3

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The retail prices of the chia nutlets offered at local markets in Guatemala, e.g. Mercado Municipal San Lucas Sacatepéquez (Fig. 1e) – range from € (2.1-)2.6(-3.0) kg^{-1} compared to a price range of organic chia in Danish supermarket and health food retailers of € (7.5-)10.1(-23.8) kg^{-1}. The Danish retail prices depend on the country of origin, e.g. the chia products offered range from Peruvian to Ugandan with the cheapest products of African origin.

Figure 1. *Salvia hispanica*; (**a**): Experimental plot, (**b**): Sampling inflorescence of Improved Material, (**c**): Pollinator visiting *S. hispanica* inflorescence, genus *Bombus*, (**d**): Harvest of *S. hispanica* inflorescences at the FAUSAC centro experimental docentea agronomia in Guatemala City. (**e**): Chia offered at GTQ 25 per libra (= pound), approx. € 2.6 kg^{-1} at the Mercado Roosevelt, Roosevelt 12 Avenida 11 Calle zona 11, Guatemala City. Photos by Edin Alejandro Gil Esturban,

4. Discussion and Conclusions

4.1. Limitations.

Chia has great potential as a superfood. Its beneficial characteristics were known to the ancient Aztec and Mayan people. Several studies have shown that this plant has the potential to be a rich source of Omega-3, easy to use. Unfortunately, not much is known about its cultivation and agronomic practices when cultivated as a monoculture. There are few experiences in this regard. In addition, there are no varieties or hybrids, which can be recommended for different conditions. Currently, creole materials are used with a mass selection process. This factor limits

production, as it is not known how these materials will behave in different conditions worldwide. Although there is a great demand, it is necessary to develop breeding programs and agronomic practices to give a boost to this pseudo-cereal with superfood potential.

4.2. Future potential

Chia has great potential, as a superfood or functional food, for modern life. Several studies have focused on the nutritional potential and as a nutritional supplement for the prevention of diseases such as cancer, diabetes, cardiovascular diseases, inflammatory disorders and nerves, among others [4]. Its soluble dietary fibre content, helping to counteract problems of constipation, diverticula and colon cancer [38]). To do this, ingest 15 to 25 g of nutlets soaked in water for fifteen minutes, for 20 days [39]. This property has caused the commercialization of the nutlets to begin in the nineties. It is grown in Argentina, Mexico, Bolivia, Paraguay, and Australia. In 2011–2012 Argentina had a production of 35%. While Australia, Mexico, Bolivia and Paraguay participated with 15% and 3,000 ha each [40]. Nicaragua and Southeast Asian countries recently joined as producers [33]. World production has grown rapidly, an example is Nicaragua, where chia production went from 5,000 quintals (= 226.8 metric tonnes) in 2013 to 180,000 quintals (= 8,164.8 metric tonnes) in 2014 [12]. An example of the increase in Chia production is Mexico, which registered 15 hectares planted and harvested in 2006 and in 2014, it reported 16,550 ha. Due to this, Chia has a high potential to become an important crop for human consumption worldwide [41].

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