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POTENCIAL NUTRITIVO DE LAS SEMILLAS DE SOTOL (*Dasylirion cedrosanum*)

NUTRITIVE POTENTIAL OF SOTOL (*Dasylirion cedrosanum*) SEEDS

Martha M. Orozco-Sifuentes[1], J. Eduardo García-Martínez[2], Carlos A. Arévalo-Sanmiguel[2], Francisca Ramírez-Godina[1] y M. Humberto Reyes-Valdés[1]*

[1]Doctorado en Recursos Fitogenéticos para Zonas Áridas, [2]Departmento de Nutrición Animal, Universidad Autónoma Agraria Antonio Narro, Saltillo, Coahuila, México.

**Corresponding author* (mathgenome@gmail.com)

SUMMARY

Agriculture in the 21th century faces the challenge of sustainable food production in a scenario of climate change. While highly caloric processed foods increase, there is a deficiency of micronutrients, fiber and good quality protein. Sustainable use of plants with wide adaptation to harsh environments can help to improve human diet. A remarkable genus for its wide adaptation, mainly in arid lands, is *Dasylirion*. It comprises a group of plants commonly called sotoles, broadly distributed in arid zones of Mexico and Southern United States. The use of this wild, albeit cultivable plant, is mainly for production of an alcoholic spirit called sotol. The study of the nutritional content of *Dasylirion* seeds can give an added use to this genus. The purpose of this research was to assess the nutritional quality of the seeds of an abundant species of this group, *D. cedrosanum.* Bromatological and mineral analyses were performed in populations from the states of Coahuila and Zacatecas, in Mexico. Samples were taken from three locations, with the harvest of the seeds three plants per site and triplicate determinations with whole wheat flour control. The sotol flour had higher protein content (27.7 %), 7 times more fat (18.4 %) and 10 times more fiber (16.2 %) than wheat flour. Additionally, sotol flour had 35 times more Ca, six times more Fe and three times more Zn and Cu than wheat flour. Although these remarkable nutritional parameters were consistent across locations, the Buenavista site plants showed the highest nutritional values. These results indicate that sotol seeds have a good potential as food and feed for humans, cattle and poultry.

Index words: *Dasyliron cedrosanum*, fats, minerals, proteins, seed, sotol.

RESUMEN

La agricultura en el siglo XXI enfrenta el desafío de la producción sostenible de alimentos en un escenario de cambio climático. Mientras que los alimentos procesados altamente calóricos aumentan, hay una deficiencia de micronutrientes, fibra y proteínas de buena calidad. El uso sostenible de plantas con una amplia adaptación a entornos hostiles puede ayudar a mejorar la dieta humana. Un género notable para su amplia adaptación, principalmente en zonas áridas, es *Dasylirion.* Comprende un grupo de plantas comúnmente llamado sotoles que se distribuyen ampliamente en las zonas áridas de México y el sur de los Estados Unidos de América. El uso de esta planta silvestre, aunque cultivable, es principalmente la producción de una bebida alcohólica llamada sotol. El estudio del contenido nutricional de las semillas de *Dasylirion* puede dar uso agregado a este género. El propósito de esta investigación fue evaluar la calidad nutricional de la semilla de una especie abundante de este grupo, *D. cedrosanum.* Se realizaron análisis bromatológicos y minerales en poblaciones de los estados de Coahuila y Zacatecas, en México. Se tomaron muestras de tres localidades, con la cosecha de las semillas de tres plantas por sitio y determinaciones por triplicado con harina integral de trigo como control. La harina de sotol presentó mayor contenido de proteínas (27.7 %), 11 veces más grasa (18.4 %) y 10 veces más fibra (16.2 %) que la harina de trigo. Además, la harina de sotol presentó 35 veces más Ca, seis veces más Fe y tres veces más Zn y Cu que la harina de trigo. Aunque los parámetros nutricionales notables fueron consistentes en todas las ubicaciones, las plantas del sitio de Buenavista mostraron los valores nutricionales más altos. Estos resultados muestran el potencial de las semillas de sotol como alimento para humanos, ganado y aves de corral.

Palabras clave: *Dasyliron cedrosanum*, grasas, minerales, proteína, semilla, sotol.

INTRODUCTION

World population projections for 2050 indicate that the number of inhabitants will reach more than nine billion, i.e. a growth of more than 1.5 billion starting from 2018 (FAO, 2009; Worldometers, 2018). This implies a growing need of food production, which, albeit steadily increasing, the trend in many countries has been toward high-energy diets with excessive saturated fat, sugar, and salt, while poor in dietary fiber and micronutrients (FAO, 2009). Also, increasing demand for animal-based protein requires more water and land, and it is expected to have negative environmental impacts. To address these demands, sustainable production of existing protein sources and the exploration of alternative sources are an urgent necessity (Henchion *et al.*, 2017). A critical factor to consider in this endeavor is climate change, which translates into increasingly extreme and frequent weather events, heat waves, droughts, and sea-level rise. The "climatic-smart agriculture approach", CSA (FAO, 2010), suggests strategy adjustments, which include modifying planting timing, adopting heat and drought resistant germplasm and developing new genotypes (FAO, 2016). It is projected that

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cropping changes will occur due to the introduction of new crops adapted to the changing climate, with or without the loss of current crops (Newbery *et al.*, 2016).

A remarkably versatile group of species, with a high range of adaptation, is the genus *Dasylirion*, which comprises plants distributed in arid and semi-arid zones of Northern Mexico and the Southern United States. These plants are perennial, dioecious and polycarpic; they are found mainly in wild populations, although some have been eventually established under cultivation. The common name of the individuals of this genus is sotol (singular) or sotoles (plural). They have short stalks up to 1.5 m in height, and long, flexible, rosette leaves stemming from the stalk, with pencil-like tips and thorny edges. Their floral scapes or sticks can reach up to 5 m in height, comprising an inflorescence of small flowers inside panicles and elliptical narrow fruits. The individuals allocate into two reproductive forms: males and females, being a dioecious genus.

Mexico has 22 sotol species distributed mainly along the Chihuahuan Desert encompassing the states of Chihuahua, Coahuila, Durango, Nuevo Leon and Zacatecas (Bogler, 1998; The plant list, 2013; Villarreal-Quintanilla *et al.*, 2016). *D. cedrosanum* (Figure 1) is the most abundant species from the *Dasylirion* genus. This species grows in basins and mountain ranges on high plateaus with extreme geographical and climate conditions (IMPI, 2002). There are vestiges indicating that sotol was an important part of the human diet in the American prehistory (Short *et al.*, 2015), where natives cooked the stalk in pits filled with hot stones. Although there is no scientific literature regarding pollinators in sotol, a role of this plant group on the maintenance of pollinator insects can be envisioned according to previous field observations (Reyes-Valdés *et al.*, 2019).

Currently, sotol serves mainly as the raw material to prepare an alcoholic beverage called sotol in Mexico, which is produced for the domestic and export markets (IMPI, 2002). Additionally, local people use the leaves to weave baskets and feed cattle during droughts. Studies related to *Dasylirion* have focused on the stem chemical composition (De la Garza *et al.*, 2010), distribution and diversity of the species (Encina-Domínguez *et al.*, 2013), sex distribution (Reyes-Valdés *et al.*, 2017) and genetic diversity (Pinales-Quero *et al.*, 2017), but there is no research focusing on the seed chemical composition.

Seed production is variable among sotol plants, each one can produce between 0.25 and 2.7 kg on inflorescences with about 95,000 seeds per kg (Reyes-Valdés *et al.*, 2012). They are dark-brown trigons with flat and rough surfaces, which must be harvested once the inflorescence reaches maturity and before seeds begin shedding (Sierra-Tristán and Morales-Nieto, 2003). Seeds are the only propagation means of this plant and a source of food for birds and other wild animals. The only previous research work on sotol seeds focuses mainly on their germination capacity (Villavicencio-Gutiérrez *et al.*, 2007) but there is no previous information on their potential as food or feed.

One of the characteristics of the spermatophytes is their capacity to transform a percentage of the energy concentrated on the seeds in the form of proteins, carbohydrates, and lipids. Overall, seeds are sources of different lipid compounds, including fatty acids, tocopherols, triglycerides, phospholipids, and sterols. Depending on the species, such compounds have different concentrations (Matthäus *et al.*, 2003). Lipids are essential elements in human and animal diet, particularly polyunsaturated fatty acids with double-bond structures. Such acids are not synthesized by the human body, although they are essential for cell membrane physiological processes, immunological functions, molecular synthesis and the regulation of inflammatory processes (Khakbaz and Klauda, 2015). Seeds have a variable quantity of important proteins that help in the development of human cellular structures and metabolism (Herman, 2014). Some plants (Román-Cortés *et al.*, 2018) and seeds (Rosales-Serna *et al.*, 2019) have elements of great importance to humans, including macro and microelements like iron (Fe), which is important for cell growth and metabolism; magnesium (Mg), which takes part in the formation of neurotransmitters and in the co-enzymes performance; manganese (Mn), an important element in enzymatic formation; zinc (Zn), necessary for the immune system; copper (Cu), contributing to red cell formation; calcium (Ca) for bone and teeth formation, and an indispensable element for blood coagulation; and phosphorous (P), which is a constitutive element of energy molecules like ATP and to ADP (Tyler and Zohlen, 1998).

Aiming to the sotol potential use as a food and feed source, the purpose of this research was to determine the nutritional content of its seeds in three locations in Northeast Mexico, and evaluate the possible effects on the site.

MATERIALS AND METHODS

Seed collection and processing

Seeds of *D. cedrosanum* were collected from three locations of Northeast Mexico, at the end of 2011 and 2015 summer seasons: Buenavista, Coahuila (25º 20' 56.86" N, 101º 2' 16.49" W; 1769 masl); San Miguel, Coahuila (25º 35' 35.80" N, 101º 5' 40.30" W; 1120 masl) and El Novillo, Zacatecas (24º 43' 2.80" N, 101º 30' 7.90" W; 1945 masl)

Figure 1. Female sotol plant (*D. cedrosanum*) with seeds along a flower stalk on a hillside in the Southeast Coahuila.

(Figure 2). Three reproductive female plants were randomly chosen per location; their inflorescences were harvested and their seeds extracted. Seeds husks were eliminated by hand, rubbing seeds between two wooden blocks, followed by a blowing process to eliminate husk residues. The seeds were air-dried for 24 h and kept in paper bags covered with sealed plastic under refrigeration at 4 ºC, until processing. Analyses were carried out with 100-g seed samples per plant, ground in a Thomas-Wiley Model 4 mill (Arthur H. Thomas Company, Philadelphia PA, USA) and kept in clean, dry plastic containers under refrigeration at 4 ºC until processing. The seed flour was analyzed according to the international standard techniques manual of the AOAC (2012). For each sample and control, the analysis was done with three replicates. Bread wheat flour was used as a control.

Proximal analysis

Total dry matter (TDM, %). An amount of 2 g of sotol seed flour was placed in a ceramic crucible of known weight before drying them into a stove at 100-105 ºC until reaching a constant weight (ISTA, 2018). Wheat was used as control (bread wheat experimental line of the Cereal Program of the Universidad Autónoma Agraria Antonio Narro) with three replicates. The following calculation was used: TDM (%) = [(crucible weight with dry matter - crucible weight) /sample in g] × 100. The moisture content (H %) was obtained by difference, using the following calculation:

$$H (\%) = 100 – TDM (\%).$$

Ash content (A, %). It was obtained by incinerating 2 g of seed flour in a muffle at 600 ºC until reaching constant weight. The following calculation was used:

A (%) = [(crucible weight with ashes - crucible weight)/ sample in g] × 100.

Raw protein content (RP, %). The Kjeldahl method (AOAC, 2012) was applied to determine the nitrogen content. A conversion factor of 6.25 was used to calculate seed flour protein content.

Ether extract or fat content (EE, %). The Soxhlet method was used for total fat extraction in Erlenmeyer flasks before processing in a siphon for 16 h (AOAC, 2012).

Raw fiber content (RF, %). Raw fiber content was obtained by acid digestion with 0.2 N H_2SO_4 followed by basic digestion with 0.3 N NaOH and muffle incineration at 600 ºC until reaching a constant weight (AOAC, 2012).

Nitrogen-free extract (NFE). This component, expressed in percentage, was determined by a difference with the rest of the determinations, where:

$$NFE = 100 – (A + RP + EE + RF)$$

Mineral content

Mineral content determinations were carried out in sotol seed flour and compared with wheat flour with three replicates. A settleable solid solution was prepared in distilled water at 1 %. In order to obtain settleable solids, 1 g of seed flour was mixed with 40 mL of nitric acid (HNO_3) and perchloric acid ($HClO_4$) 3:1. The blend was heated (at 550 ºC) until the sample was completely digested leaving behind a white residue (non-dissolved solids) which was washed with de-ionized water, and filtered through Whatman paper #42. The filtered solution was calibrated with 100 mL of de-ionized water. The non-dissolved solid solution (1 %) was introduced into a Varian AA-1275 series

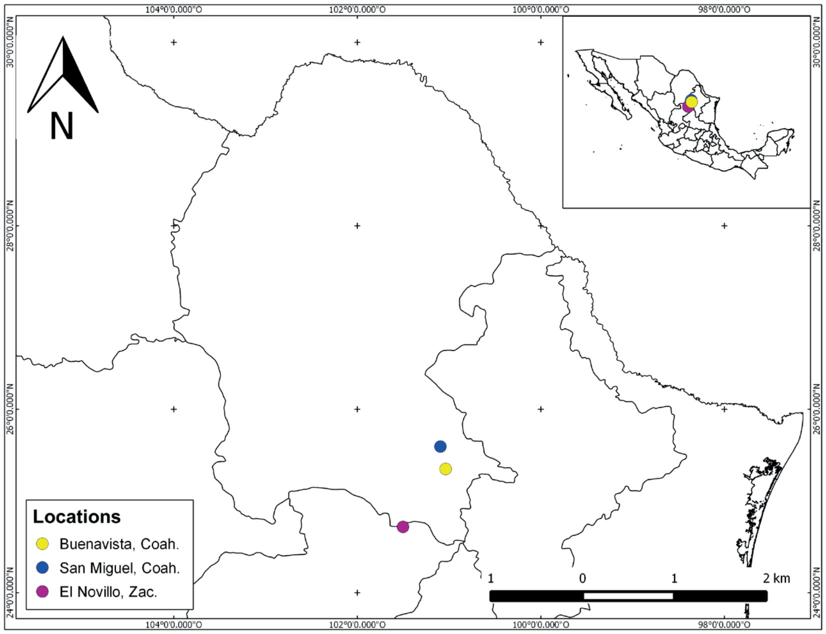

Figure 2. Geographic locations of the sampling sites of sotol seeds (*D. cedrosanum*) in Southeast Coahuila and Northern Zacatecas.

atomic absorption spectrophotometer, using hollow-cathode lamps (multi-elemental and single-element) to detect the minerals in every sample at a given wavelength (λ) (AOAC, 2012). For most elements, acetylene gas (C_2H_2) was used, as well as air to detect calcium (Ca), nitrous oxide (N_2O) and acetylene (C_2H_2). Depending on the minerals under analysis, standard solutions were prepared for each element at 1, 2 and 3 ppm.

The atomic absorption spectrophotometer measured the concentration of each element in ppm, which multiplied by the dilution factor (0.1), gave the concentration of every element in mg g^{-1}. To determine phosphorous from the non-dissolved solid solution at 1 %, 1 mL of the sample was poured into a 15 × 100 mm test tube; afterwards, 5 mL of ammonium molybdate $(NH_4)_6Mo_7O_{24} \cdot 4\ H_2O$ and 2 mL of amino naphthol sulfonic acid (ANSA) were added. The blend was stirred with a vortex and allowed to rest for 20 min. Spectrophotometer readings were taken at 640 nm. A calibration curve at 20, 40, 60, 80 and 100 ppm, based on a phosphorous standard, was used to determine the concentration of each element.

Statistical analysis

Mineral and nutritional sotol contents across locations and wheat were compared by a one-way analysis of variance (ANOVA). When statistical significance was found, means were compared by the Tukey HSD test (Steel and Torrie, 1960). Data formatting and analysis were carried out with the language and environment for statistical computing R (R Core Team, 2018).

RESULTS

Proximal analysis

Table 1 compares the nutritional content of sotol seed flour and the wheat flour, with percentage values based on 100-g samples. Overall, mean values for dry matter (91.0 %), moisture (9.0 %) and ash (2.2 %) in sotol seeds were very close to the average percentages found in wheat (90.2 % dry matter, 9.8 % moisture; and 2.1 % ash), without statistical significance; however, protein (27.7 %), fat (18.4 %) and fiber (16.2 %) contents were significantly higher ($P \le 0.05$) in sotol flour than in wheat (16.0 % protein, 1.6 % fat, and 1.7 % fiber). The nitrogen-free extract, mostly made out of soluble carbohydrates and starch, was significantly higher ($P \le 0.05$) in wheat flour (78.6 %) than in sotol flour (35.5 %). For dry matter, the Buenavista seeds showed significantly higher values than those from El Novillo. Consequently, seeds from El Novillo showed higher moisture values than those from Buenavista ($P \le 0.05$). For raw protein, the material recollected from Buenavista had significantly higher ($P \le 0.05$) raw protein values (30.5 %) than El Novillo (25.0 %). As for ash percentage, the records from Buenavista were higher than those of the two remaining locations. No significant differences were found for ether extract among the three locations. For raw fiber, seeds collected in Buenavista showed significantly

Table 1. Nutritional content of *D. cedrosanum* seeds from two locations in Southeast Coahuila and one in Northern Zacatecas. The results are based on 100 g of seed flour.

Location	Dry matter	Moisture	Raw protein	Ash	Ether extract	Raw fiber	Nitrogen-free extract
				(%)†			
Buenavista	91.6 ± 0.2 a	8.4 ± 0.2 b	30.5 ± 1.0 a	2.4 ± 0.0 a	16.9 ± 0.3 a	14.2 ± 0.5 b	36.0 ± 1.5 a
San Miguel	90.8 ± 0.1 ab	9.2 ± 0.1 ab	27.5 ± 1.1 ab	2.1 ± 0.0 b	17.8 ± 1.0 a	16.8 ± 1.2 ab	35.8 ± 1.8 a
El Novillo	90.5 ± 0.2 b	9.5 ± 0.2 a	25.0 ± 0.6 b	2.1 ± 0.0 b	20.5 ± 1.4 a	17.8 ± 0.7 a	34.6 ± 0.3 a
Average (sotol)	91.0 ± 0.1	9.0 ± 0.0	**27.7 ± 0.6**	2.2 ± 0.0	**18.4 ± 0.6**	**16.2 ± 0.5**	35.5 ± 0.1
Control (wheat)	90.2 ± 0.0	9.8 ± 0.1	16.0 ± 0.0	2.1 ± 0.0	1.6 ± 0.0	1.7 ± 0.1	**78.6 ± 0.7**

Values are means ± standard error. † Means within columns followed by the same letters are not statistically different (Tukey, 0.05). For sotol and wheat averages, numbers in bold font are significantly higher than their counterpart (Tukey, 0.05).

lower values ($P \leq 0.05$) than those from the remaining two locations. There were no significant differences in nitrogen-free extract among locations.

Mineral analysis

Table 2 shows the mineral content (macro-elements) of sotol and wheat flours. Mean contents for K (3.6 mg g^{-1}), Mg (1.8 mg g^{-1}) and P (2.9 mg g^{-1}) in sotol flour were very similar to those found in wheat, K 3.9 mg g^{-1}, Mg 2.0 mg g^{-1} and P 2.5 mg g^{-1}, without statistically significant differences. On the other hand, Na (1.7 mg g^{-1}) was much higher, and Ca (7.0 mg g^{-1}) was 35 times greater than the concentrations determined for wheat (Na 0.04 mg g^{-1} and Ca 0.2 mg g^{-1}). No significant differences were observed among locations regarding K, Na, Mg and P contents, but there were differences in Ca content: Buenavista (7.3 mg g^{-1}) and San Miguel (7.3 mg g^{-1}) seeds had significantly higher Ca concentration than seeds from El Novillo (6.5 mg g^{-1}).

Table 2 also shows the microelement contents of sotol seed flour and wheat flour. Average contents of Zn (79.2 μg g^{-1}), Fe (55.6 μg g^{-1}) and Cu (19.4 μg g^{-1}) in sotol flour were significantly higher than those in wheat (Zn 31.6 μg g^{-1}, Fe 8.0 μg g^{-1} and Cu 4.0 μg g^{-1}), while Mn content was significantly higher in wheat (29.6 μg g^{-1}) than in sotol flour (11.22 μg g^{-1}). There were no significant differences among locations regarding Fe, Cu and Mn; however, there were differences in Zn with Buenavista seed content (90.0 μg g^{-1}) being higher than those from El Novillo (Zn 67.6 μg g^{-1}).

DISCUSSION

One of the important factors in seed preservation and seed storage is moisture content. In cereals, the ideal moisture percentage to prevent insect development is between 10 and 15 %. Low moisture contents, as well as temperatures lower than 10 ºC help to avoid seed deterioration under storage because minimum water conditions impair the development of microorganisms like fungi, bacteria, and insects (Rao *et al.*, 2007; Roberts and Ellis, 1989). Sotol seeds moisture contents (9 %) were similar to the moisture contents found in wheat. The moisture content found in wheat seeds agrees with the reported composition tables (9.1 %) (Muñoz, 2010); however, this parameter can vary according to the drying process of seeds after harvesting.

Average protein content in sotol seeds (27.7 %) exceeded by far the content in wheat flour (16.0 %), even though the values found in wheat were moderately higher than the reported (10.6 %) by Muñoz (2010). The high protein content in sotol implies a greater content of amino acids, as well as the potential presence of enzymes, whose importance depends on their functionality. Wheat has some hydrolytic enzymes that breakdown carbohydrates, such as α and β- amylases, and other proteolytic enzymes that include lipases, esterases, phosphatases, phytases and lipoxygenases (Koehler and Wieser, 2013). There is no background literature referring to the nutritional content of sotol seeds; thus, the type of proteins is unknown. Besides wheat, the sotol protein content was higher than the reported in other important cereals such as corn (*Zea mays* L.) (9.4 %) and rice (*Oryza sativa*) (7.4 %) (Muñoz, 2010). On the other hand, the protein content of sotol seeds from different locations had significant, albeit small differences. Differences in the protein content of samples from different locations might originate from the fact that Buenavista plants have better distribution and irrigation, which translates into higher availability and higher flow of nitrate (NO_3), or ammonium nitrogen (NH_4^-) in the soil, leading to a superior plant nitrogen uptake.

Overall, ash content represents the inorganic matter or the mineral concentration in food. There were significant differences in ash among locations, with Buenavista showing higher levels of minerals than San Miguel and El Novillo. Ash percentage greatly depends on the

Table 2. Mineral content in ***D. cedrosanum*** seeds from two locations in Southeast Coahuila and one in Zacatecas. The results are based on 100 g of seed flour.

Location	K	Na	Mg	Ca	P	Zn	Fe	Cu	Mn
	Macroelements (mg g^{-1})†					Microelements (µg g^{-1})†			
Buenavista	4.2 ± 0.1 a	1.3 ± 0.1 a	2.0 ± 0.4 a	7.3 ± 0.1 a	3.4 ± 0.1 a	90.0 ± 4.3 a	71.0 ± 8.8 a	20.6 ± 1.8 a	12.0 ± 0.5 a
San Miguel	3.4 ± 0.8 a	2.3 ± 0.1 a	2.2 ± 0.2 a	7.3 ± 0.1 a	2.6 ± 0.1 a	80.0 ± 4.6 ab	47.0 ± 4.9 a	17.3 ± 0.8 a	10.0 ± 0.0 a
El Novillo	3.2 ± 0.1 a	1.4 ± 0.8 a	1.4 ± 0.3 a	6.5 ± 0.1 b	2.7 ± 0.2 a	67.6 ± 5.6 b	49.0 ± 5.1 a	20.3 ± 3.3 a	11.6 ± 0.6 a
Average (sotol)	3.6 ± 0.2	**1.7 ± 0.2**	1.8 ± 0.0	**7.0 ± 0.1**	2.9 ± 0.1	**79.2 ± 4.0**	**55.6 ± 5.0**	**19.4 ± 1.2**	11.2 ± 1.4
Control (wheat)	3.9 ± 0.3	0.04 ± 0.0	2.0 ± 0.2	0.2 ± 0.0	2.5 ± 0.2	31.6 ± 1.4	8.0 ± 0.5	4.0 ± 0.0	**29.6 ± 0.4**

Values are means ± standard error, †Means within columns followed by the same letters are not statistically different (Tukey, 0.05). For sotol and wheat averages, numbers in bold font are significantly higher than their counterpart (Tukey, 0.05).

composition or type of soil where the species grows (Hidalgo *et al.*, 2009).

Fat content in sotol seeds was 11 times higher (18.4 %) than that in wheat (1.6 %). Muñoz (2010) reports a value for wheat (2.6 %), close to the one recorded in this research. Fat content in sotol flour implies a high probability of finding lipids that are nutritionally important. In general, seeds have fatty acids that provide consistency and structure to food; they also contribute with aroma, flavor, color and the sensation of satiety. Among fatty acids, the most beneficial are polyunsaturated acids, with more than one double bond, including linoleic acid (Omega 6, C18:2n6c) and linolenic acid (Omega 3, C18:3n3) (Calder, 2001). These acids are very important because the human body cannot synthesize them, and food is their only source. They are precursors of acids like eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids that have many beneficial health effects. As a part of the human diet, these acids reduce the risk of cardiovascular diseases, improve neurotransmission by enhancing synapsis function and help inhibiting the growth of cancer cells (Mantzioris *et al.*, 2000).

Non-digestible and non-absorbable fiber particles serve as vehicles to other nutrients. They add volume to the diet and help to eliminate waste. Sampled sotol seeds had 10 times more fiber (16.2 %) than wheat (1.7 %). Muñoz (2010) reports a fiber content in wheat of 3.3 %, which is not far from the one found in this research.

Nitrogen-free extract (mainly made of soluble carbohydrates, starch and hemicellulose) has been found at high concentrations in cereals like wheat, sorghum (*Sorghum* spp.) and corn (Surco and Alvarado, 2010). Sotol contained (35.5 %), comparatively less than half compared to wheat (78.6 %). In food composition tables, wheat values (73.4 %) (Muñoz, 2010) are close to the ones found in this work.

Minerals participate in a great number of functions, both in plants and humans. Macronutrients (K, Na, Mg, Ca y P) are found in plant tissues at concentrations greater than 0.1 % on a dry matter basis (Marles, 2017; Martínez-Ballesta *et al.*, 2010). Calcium is one of the most valuable human nutritional elements, and in combination with phosphorous, provides strength to bone structures. Breast milk contains 32 mg of calcium per every 100 g. In sotol seed flour, the calcium concentration reached 7.0 mg g^{-1}, while in wheat flour the calcium concentration was 0.2 mg g^{-1}. Therefore, 100 g of sotol seed flour have 700 mg of Ca; 35 times more Ca than wheat (20 mg per 100 g) and 23 times more Ca than breast milk. The levels of daily-recommended Ca intake for children are 400 to 700 mg and the daily-recommended Ca intake for adults is 400 to 500 mg. It is not know yet if calcium in sotol can be digested. It is, therefore, necessary to study the nature of this important nutritional macro-element to assess its availability for nutritional purposes (Latham, 1997).

Iron is one of the microelements found in low levels in human beings (3 to 4 g in adults, on body weight basis g kg^{-1}). Iron's main task is carrying oxygen, and the body loses 1 mg a day. Breast milk has 2 mg of iron per liter; which is a relatively low quantity since the recommended daily intake is 15 mg (women in fertile age). Sotol seeds contain 5.5 mg 100 g^{-1} of iron, which is higher than wheat (0.8 mg 100 g^{-1}) and higher than breast milk (2 mg L^{-1}) contents (Latham, 1997).

Zinc is one of the elements of essential enzymes in human metabolism. Lack of zinc can lead to congenital diseases and growth impairments in human beings. Zinc recommended daily intake in adults is 15 mg. Sotol flour had 79.2 µg g^{-1} of zinc concentration, while wheat had only 31.6 µg g^{-1}; therefore, sotol flour has two times more zinc than wheat flour, offering the potential benefit of contributing with additional nutrients to human and animal diet.

Sodium and potassium are salts found in body liquids. Sodium is extra-cellular, potassium is intra-cellular, and both take part in the osmotic regulation process. Na was higher (1.7 mg g^{-1}) in sotol flour than in wheat (0.04 mg g^{-1}).

Phosphorous is one of the important nutritional macro-elements and it is mainly found in bones and teeth, in 1:2 ratio with Ca, which forms part of the molecules involved in energy metabolism like ATP and also triggers reactions in different parts of the body and forms part of cell membranes. The recommended-daily intake in adults is 800 g. Sotol flour (2.9 mg g^{-1}) and wheat flour (2.5 mg g^{-1}) had very similar low phosphorous quantities. The inclusion of other types of food in the diet can supplement those low phosphorous quantities. In brief, the contents of Ca, Na, Zn, Fe and Cu were higher in sotol than they were in wheat flour.

Regarding P, Mg and K, the sotol and wheat concentrations were very similar with no significant differences, while Mn was higher in wheat than in sotol. The mineral composition varies among crops and greatly depends on the soil where they grow. Regarding the content of nutrients in sotol seed flour, it can be said that sotol has the potential to contribute with macro and micronutrients to human and animal diet, provided that further analysis discards the presence of anti-nutritional elements that can restrict its use as food and feed source. The minerals concentration obtained from wheat coincide, with those reported by Muñoz (2010) in tables of food composition.

CONCLUSIONS

Sotol seeds contain remarkable amounts of protein, fat, fiber and ash, compared to those of wheat, a cereal widely used for human consumption. Sotol seeds are a potential source of amino acids to human, cattle and poultry diets. Its high content of fat makes it a source of energy and a potential way to enrich the fatty acids in food and feed. The mineral concentration in sotol seeds for Ca, Na, Zn, Fe and Cu is higher than that those in wheat, being also a potential source of macroelements and microelements in the diet. Although some variation was found across locations in the nutritional components of sotol seeds, their abundance was in general stable. The environmental characteristics of the localities can affect the protein content. Sotol seeds have the potential to contribute with macro and micronutrients for food or feed, provided that further analysis excludes the presence of anti-nutritional elements that may restrict its use.

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