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SOIL CHARACTERISTICS AND SALICYLIC ACID SUPPLEMENTATION IN CASTOR BEAN (*Ricinus communis* L.) OIL PRODUCTION

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ABSTRACT

Castor bean (*Ricinus communis* L.) is an oleaginous plant of economic importance due to its different industrial applications. Edaphic characteristics are used to determine the viability of places considered as suitable to obtain castor oil. The objectives of this study were to determine the edaphic characteristics and oil content of *R. communis*, and to evaluate elicitation with salicylic acid (SA) in El Marqués, Querétaro, Mexico. Sampling was carried out in a direct way, selecting sites where castor bean plants were found. Samples of 1.5 kg of soil were taken and 3 clusters of castor bean in a mature state were collected from 21 accessions. The physicochemical characteristics of the soil and oil content of seeds were determined. Finally, 300 plants of the Guanajuatoil variety were planted and elicitated with different SA concentrations under greenhouse conditions in order to determine oil content. The physical analysis of the soil samples indicated dark-colored soils, Mollisol and Vertisol types, with different textures: clay, clay loam, sandy clay loam and sandy loam. Soil chemical analyses showed the following soil characteristics: pH 7.22; electrical conductivity 0.52 dS m^{-1}; organic matter 7.17%; cation exchange capacity 26.77; calcium 38.62, magnesium 6.81, sodium 13.41and potassium 6.97 cmol kg^{-1}; and nitrogen and phosphorus contents of 16.32 and 54 mg kg^{-1}, respectively. Castor oil content was higher in clay soils (41.46%). The plants elicited with SA presented oil contents ranging from 28.99% to 52.9%, obtained with 100 and 900 µM. In conclusion, elicitation with SA is an adequate method to increase oil content in castor bean seeds. The locality of El Marqués has good potential for the production of castor oil.

Keywords: castor oil, Mollisol, Vertisol, elicitation.

INTRODUCTION

In Mexico, castor bean (*Ricinus communis* L.) is found in the wild, being extensively distributed in most states of the country (Goytia-Jiménez et al., 2011). It is an agricultural species with both agronomic and technological advantages, such as habitat in marginal areas, low water requirement, high yield potential, a wealth of genetic resources for variety selection, and lack of competition with human food production (Hurtado Salazar et al., 2013). In addition, growing castor bean plants can provide various environmental benefits such as soil protection, increased soil organic matter, erosion prevention and enhanced moisture content (Fadhil et al., 2017).

Castor bean grows well in areas of intermediate and high fertility with deep, loose, permeable, aerated and well-drained soils, high levels of nutrients and a pH level of 5.5 to 6.7 (Ramírez et al., 2017). Its cultivation requires medium-textured soils, such as loam or sandy loam, with high organic matter content and a depth of 60 cm (the optimum depth for the development of the main root is 150 cm) (Hernández-Martínez and Montes-Hernández, 2018). In general, castor beans do well on either acidic or alkaline soils with good drainage conditions (Vashist and Ahmad, 2011). This plant can recover soils where crops such as corn, beans and sorghum have been established, being nitrogen content the most important factor to consider in fertility level when establishing this crop (Yeboah et al., 2020).

As most of its plant parts are used, castor bean has several applications. The stems are used to produce paper, while the seeds are used to obtain castor oil (Naik et al., 2018). In addition, the bagasse that remains after oil extraction can be used as an organic fertilizer. Finally, leaves and seeds can be used as ingredients of extracts for pest control (Ramos-López et al., 2012; Mubofu, 2016).

Distilled castor oil has industrial applications due to its high content of ricinoleic acid (89%), which makes it an important raw material for the oleochemical industry, especially in developed countries (Vasco-Leal et al., 2018). The oil has been used as a lubricant for aircraft and hydraulic fluid and in the preparation of soaps, linoleum, printing ink, nylon, varnishes, enamels, paints, and electrical insulation (Sanz et al., 2019).

One of the strategies to increase oil content in castor seeds is elicitation. This technique involves induction of the immune system by the addition of elicitors, which results in improved plant protection, productivity, and quality (Luciano et al., 2017). Salicylic acid is a well-known biotic elicitor when applied exogenously to different plant species, increasing the content of different primary and secondary metabolites, including fatty acids (Subban et al., 2019). According to Hernández-Martínez and Montes-Hernández (2018), the Guanajuatoil variety can be sown in soils such as Regosols, Mollisols, Rendzinas and Vertisols, recording oil yields of 44%.

The objectives of this study were to determine the edaphic characteristics and oil content of *R. communis* (Guanajuatoil variety), and to evaluate the elicitation with salicylic acid in El Marqués, Querétaro, Mexico.

MATERIALS AND METHODS

Geographical localization of the study area

Castor bean (*Ricinus communis* L.) clusters were collected from 21 accessions (Table 1) during the seasons of autumn and winter 2019 in El Marqués, Querétaro, Mexico. Then, 1 accession was planted in a greenhouse at the Autonomous University of Querétaro, Amazcala Campus. Accessions were selected using the cartography system elaborated by the National Institute of Geography and Informatics Statistics (INEGI, 2016) by consulting climate, precipitation, temperature, topography, geology, soil science, land use and vegetation charts at a scale of 1:250,000, to verify that the accessions met the inclusion criteria and to assess the productive potential of the species, and the characteristics of the study area. The accessions were evaluated in the field along specific routes. Google Earth Pro (Menlo Park, California, USA) was used to interpret the satellite images.

The coordinates and altitude were recorded at each sampling accession using a Magellan global positioning system (GPS, model eXplorist 610, San Dimas, California, USA).

A random systematic sampling was carried out in a direct way, selecting sites where castor plants and a neighboring crop were found. Soil samples of 1.5 kg of soil were taken by making a hole of 30 x 30 cm and placed in plastic bags. In addition, 3 clusters of castor bean in a mature state were collected from 21 accessions and placed in paper bags. Both soil and cluster samples were kept at room temperature and transferred to the corresponding laboratory for analysis.

Study material

The soil samples were identified by site and taken to the Soil Laboratory of the Autonomous Metropolitan University Department of Man and Environment of the Xochimilco Unit. The soil samples were dried at room temperature, sieved with a 2 mm nylon mesh, and placed in polyethylene bags.

The physicochemical analyses of the soil samples were carried out in accordance with the Official Mexican Standard 021 RECNAT-2000, which establishes the directions for fertility, salinity and soil classification, sampling, and analysis. The physical properties measured were wet and dry color, bulk density (ρb), real density (ρs), total porosity (*f*) and texture. The chemical properties measured were as follows: pH, electrical conductivity (EC), organic matter (OM), inorganic nitrogen (N), available phosphorus (P), and cation exchange capacity (CEC). The cluster samples were allowed to dry in the shade for two weeks at room temperature in paper bags. They were husked to obtain the seeds, which

Table 1. Location of the study sites in El Marques, Queretaro.

Site	Location	Location Coordinates (North and West)		Altitude (mamsl)	Crop
1	La Griega 1	20°36′1.9″ N	100°12′49.7″ W	2017	Maize
2	Aeropuerto	20°38′38.8″ N	100°13′46.7″ W	2060	Maize
3	Granja de Composteo	20°38′26.5″ N	100°13′0.37″ W	2062	Maize
4	Juzgado Especializado	20°40′54.9″ N	100°21′70.9″ W	2140	Maize
5	Carretera a San Miguel de Allende	20°43′03.31″ N	100°20′28.8″ W	2062	Maize
6	Hangares	20°36′41.4″ N	100°09′18.2″ W	2097	Maize
7	La Cruz	20°43′38.6″ N	100°18′0.1″ W	2125	Maize
8	Carretera Amazcala	20°42′36.8″ N	100°16′5.9″ W	2089	Maize
9	Carretera Campus Amazcala UAQ	20°43′0.2″ N	100°15′32.9″ W	2100	Bean
10	La Griega 2	20°38′52.3″ N	100°13′56.8″ W	2032	Bean
11	Aut. Qro-San Juan del Río	20°31′08.9″ N	100°10′0.1″ W	1990	Maize
12	Limite Municipal	20°30′40.2″ N	100°09′18″ W	1906	Maize
13	Zona industrial	20°34′27″ N	100°17′44.8″ W	1960	Sorghum
14	Campamento de conservación	20°33′36.1″ N	100°13′36.4″ W	1983	Sorghum
15	La Palma	20°32′21.17″ N	100°11′41.90″ W	1955	Oat
16	El Marqués	20°36′30.4″ N	100°15′2.8″ W	1968	Barley
17	Parque industrial	20°37′52.7″ N	100°16′33.6″ W	2009	Maize
18	San Vicente Ferrer	20°46′27.2″ N	100°21′2.20″ W	2023	Nopal
19	Carretera 500 entronque 510	20°43′10.5″ N	100°16′42″ W	2013	Vegetables
20	Rancho La Quita	20°44′35.1″ N	100°16′47.9″ W	2055	Maize
21	Campus Amazcala UAQ	20°42′18.6″ N	100°15′57.2″ W	2106	Tomato

were then dried in a solar dryer for one week at room temperature Then, quantitative analyses of calcium exchangeable cations (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}) were performed.

Castor oil extraction

The clusters of the plants were identified by site, and the samples were transferred to the Laboratory of Natural Insecticidal Compounds of the Faculty of Chemistry of the Autonomous University of Querétaro, where they were stored in polyethylene bags under controlled temperature conditions.

Twenty grams of seeds were weighed with an analytical balance (Ohaus PA323C, Melrose, MA, USA), crushed with a porcelain mortar and placed in a filter paper cartridge Whatman No 1 filter (Schenectady, NY, USA). Soxhlet extraction was performed with an apparatus with 300 ml of technical grade n-hexane (Sigma-Aldrich, Toluca, State of Mexico, Mexico). The sample was heated to the boiling point (69 °C) for 12 h and allowed to cool at room temperature to obtain oil samples. The solvent was removed under reduced pressure in a rotary evaporator IKA RV 10 basic (Staufen im Breisgau, BW, Germany) (Sbihi et al., 2018).

The castor oil produced by the seeds was estimated by measuring the mass of the oil obtained.

Elicitation of castor bean

A total of 300 plants of the Guanajuatoil variety were planted under greenhouse conditions at the Autonomous University of Querétaro, Amazcala Campus. The experimental design used in the greenhouse was completely randomized. Five groups of 60 plants were treated with different concentrations of salicylic acid (0, 100, 300, 600 and 900 μM) (Sigma-Aldrich, Toluca, State of Mexico, Mexico), applied 60 days after sowing in a foliar way at point of dripping. When the plants were mature, they were harvested, and sun dried to obtain the seeds. Finally, the seeds were weighed as a composite sample of each treatment; the experiments were performed in triplicate. Oil was extracted as indicated in 'Castor oil extraction'.

Statistical analysis

A linear regression was performed using Excel software to observe the relation between oil concentration and salicylic acid concentration. Data were analyzed using a one-way analysis of variance (ANOVA) with a Tukey test ($p<0.05$) to determinate if there were differences in the oil content of the plants treated with different SA concentrations. The statistical analysis was performed using ®SYSTAT 9 software.

RESULTS AND DISCUSSION

Soil physicochemical characterization

The 21 accessions sampled in this study were located in El Marqués, Queretaro, at an altitude ranging from 1,906 to 2,140 meters above sea level. The main crop in the area was maize (Table 1). Soil color was determined according to the Munsell System for dry and soils. Dry soil corresponded to: 35% brown (10YR 5/3), 25% dark gray (10YR 4/1), 15% very dark brown (10YR 3/2), 10% black (10YR 2/1), 5% dark grayish brown (10YR 4/2), 5% yellowish brown (10YR 5/8), and 5% dark yellowish brown (10YR 3/6). Wet soil corresponded to: 50% dark brown (10YR 3/3), 25% very dark brown (10YR 2/2), 15% very dark grayish brown (10YR 3/2), 5% yellow (10YR 7/8), and 5% dark yellow brown (10YR 4/4) (Table 2).

Bulk density was very similar in all the sites sampled, ranging from 1.02 to 1.3 g cm^{-3}, with an average of 1.2 g cm^{-3}. Particle density ranged from 1.8 to 2.3 g cm^{-3}, with an average of 2.1 g cm^{-3}, while total porosity varied between 40.6% and 48.8%, with an average of 45.1%. The textural class of the accessions was as follow: clay (40%), clay loam (20%), sandy clay loam (20%), sandy loam (15%) and loam (5%). The soils corresponded to Vertisols and Mollisols, which are the two most abundant soil types in El Marqués. Thus, dark soils were the most abundant. Vertisols exhibit a dark color and lack of distinct horizons (Basga et al., 2018; Pierre et al., 2018), while Mollisols are characterized by a dark-colored mollic horizon at the top of the profile (Jiménez et al., 2012). Since castor beans grow well in loamy soils (Solís Bonilla et al., 2016), it is important to evaluated if the plants can do well in clayey and clay loam soils.

The ϱb values varied slightly, ranging from 1.0 to 1.3. These results agree with those obtained by Krasilnikov et al. (2013), who reported values between 1.1 and 1.4 g cm^{-3} in clayey soils (Vertisols); and also with those of Hernández et al. (2012), who reported values ranging from 0.9 to 1.8 g cm^{-3} in Mollisols. On the other hand, the f values observed in the present study ranged from 40.6 to 48.7%, which is in agreement with those reported by Krasilnikov et al. (2013) for clayey soils in Jalisco (45.1% and 58%).

The chemical properties of the soil samples (including pH, EC, OM, CEC, and contents of Ca, Mg, Na, K, N and P) are presented in Table 3. The average pH was 7.2 for most of the soils analyzed. Similar values were reported by Zuñiga-Silgado et al. (2020) and Rico-Rodríguez et al. (2013) in soils (Vertisols) of Morelos and Querétaro, with values of 6.6 and 7.1, respectively.

According to the Official Mexican standard

Table 2. Physical properties of the soil samples.

Site	Color		ρb	ρs	*f*		(%)		Textural
	Dry	Wet	(g cm^{-3})	(g cm-^{3})	(%)	Sand	Silt	Clay	class
1	10YR 5/3 Brown	10YR 3/3 Dark brown	1.2	2.3	48.1	45.5	20.2	34.5	Cr
2	10YR 5/3 Brown	10YR 3/3 Dark brown	1.2	2.2	46.1	35.5	26.0	38.5	Cr
3	10YR 5/8 Yellowish brown	10YR 7/8 Yellow	1.2	2.3	45.2	67.5	26.1	6.5	Ca
4	10YR 3/2 Very dark grayish brown	10YR 2/2 Very dark brown	1.1	2.1	47.0	28.2	18.1	53.8	R
5	10YR 2/1 Black	10YR 3/3 Dark brown	1.1	2.1	46.0	29.5	48.0	22.5	Cr
6	10YR 2/1 Black	10YR 3/3 Dark brown	1.1	2.0	43.6	35.5	24.1	40.5	R
7	10YR 4/1 Dark gray	10YR 3/3 Dark brown	1.1	2.0	45.4	58.2	16.1	25.8	Cra
8	10YR 3/6 Dark yellowish brown	Very dark brown	1.2	2.3	45.9	80.2	8.2	11.8	Ca
9	10YR 5/3 Brown	10YR 3/3 Dark brown	1.3	2.2	43.1	54.2	18.1	27.8	Cra
10	10YR 5/3 Brown	10YR 3/3 Dark brown	1.3	2.2	40.6	68.2	16.0	15.8	Ca
11	10YR 5/3 Brown	10YR 3/3 Dark brown	1.3	2.2	40.6	21.6	30.6	47.8	R
12	10YR 4/1 Dark gray	10YR 3/2 Very dark grayish brown	1.1	1.9	42.8	46.2	28.7	25.1	Cra
13	10YR 4/1 Dark gray	10YR 3/2 Very dark grayish brown	1.2	2.1	44.5	23.6	20.2	56.4	R
14	10YR 4/1 Dark gray	10YR 3/2 Very dark grayish brown	1.1	2.2	48.8	18.2	20.1	61.8	R
15	10YR 3/2 Very dark grayish brown	10YR 2/2 Very dark brown	1.1	1.8	41.3	28.2	19.4	52.4	R
16	10YR 4/1 Dark gray	10YR 2/2 Very dark brown	1.1	2.0	45.0	16.2	24.2	59.8	R
17	10YR 5/3 Brown	10YR 3/3 Dark brown	1.1	2.1	48.7	32.2	38.1	29.8	Cr
18	10YR 3/2 Very dark grayish brown	10YR 2/2 Very dark brown	1.1	1.9	43.5	33.6	25.3	41.1	R
19	10YR 5/3 Brown	10YR 3/3 Dark brown	1.2	2.3	47.2	48.2	26.0	25.8	Cra
20	10YR 4/2 Very dark grayish brown	10YR 4/4 Dark yellow brown	1.0	1.9	47.2	36.9	32.0	31.1	Cr
21	10YR 5/3 Brown	10YR 3/3 Dark brown	1.1	2.2	46.9	29.3	18.1	52.6	R

ρb = Bulk density; ϱs= Real density; *f*= Total porosity; R= Clayey; Cr= Clay loam; Cra= Sandy clay loam; Ca= Sandy loam.

NOM-021-SEMARNAT-2000, 12 of the 21 accessions in the present work showed neutral pH, with average values of 6.8 to 7.3; while the remaining 9 of them were classified as moderately alkaline, with pH values from 7.4 to 8.3. Sánchez et al. (2018) reported pH values that show that soils of El Marqués, Querétaro, are predominantly neutral to moderately alkaline, which is above the optimum range for castor bean (5.5 to 6.7).

EC varied from 0.22 to 0.87 dSm^{-1}, which was within the range of 'negligible salinity effects'. Previous studies have reported similar values, ranging from 0.04 to 0.04 dSm^{-1} (Luna et al., 2012) and from 0.2 to 0.3 dSm^{-1} (Rico-Rodríguez et al., 2013) in soils of Queretaro.

OM content averaged 7.1% and ranged from 3.9 to 10.0%. Among the soils under study, 20 of the 21 accessions were within the classification of organic soils (> 6.0%), while 1 accession presented high OM content (3.9%). In this sense, Pronk et al. (2017) indicated that OM content of these soils influences the growth and establishment of the species under study. Other author like Luna et al. (2012) reported OM values ranging from 0.84% to 7.53% in soils of the same place where this experiment was conducted. Finally, Rico-Rodríguez et al. (2013) reported OM values between 2.3% and 5.1% in soils of Querétaro. Values found by the authors mentioned above are similar to the results found in the present study.

CEC varied between 13.7 and 43.1 cmol kg^{-1}, with an average value of 26.8 cmol kg^{-1}. Of the 21 accessions analyzed, 10 exhibited high CEC (25.1 to 39.5 cmol kg^{-1}), 10 showed average values from 13.7 to 23.9 cmol kg^{-1}, and only 1 accession recorded a very high CEC (43.1 cmol kg^{-1}). These results are in agreement with data previously reported in the literature. For instance, values reported by Luna et al. (2012) were between 12.5 and 28.5 cmol kg^{-1}, indicating that soil from El Marqués present intermediate and high CEC. At the same time, Rico-Rodríguez et al. (2013) reported a CEC value of 12.96 cmol kg^{-1} in Querétaro. In addition, a study conducted by Guo et al. (2018) reported values of 26.1 cmol kg^{-1} in a Vertisol in China, while Luna et al. (2012) reported values ranging from 7.78 to 17.3 cmol kg^{-1} in Mexico. Furthermore, Susilowati et

Table 3. Chemical properties of the soil samples and castor oil content (%).

Site	pH	EC (dS m^{-1})	OM (%)	CEC	Ca cmol kg^{-1}	Mg cmol kg^{-1}	Na cmol kg^{-1}	K cmol kg^{-1}	N mg kg^{-1}	P mg kg^{-1}	Castor oil (%)
1	7.7	0.7	6.1	27.5	32.7	5.1	9.9	7.1	22.5	43.8	35.7
2	7.7	0.7	6.3	25.1	25.0	3.8	9.9	7.6	14.6	23.2	35.0
3	7.8	0.5	6.4	22.1	20.9	4.9	16.4	5.8	14.1	11.6	42.2
4	6.9	0.4	7.1	33.5	27.1	4.6	5.4	3.5	16.7	5.8	48.2
5	7.6	0.6	7.1	43.1	53.0	1.0	7.1	2.6	17.2	7.4	37.7
6	8.3	0.7	3.9	18.5	11.7	1.9	13.4	10.4	12.9	26.1	35.2
7	7.2	0.8	7.7	29.9	15.4	4.2	12.9	10.2	17.9	14.5	42.8
8	6.9	0.6	6.4	13.7	8.3	0.6	6.0	4.8	14.4	11.3	37.8
9	7.2	0.2	6.0	17.3	15.7	0.6	5.4	4.0	12.4	19.7	42.0
10	7.0	0.6	6.4	16.1	7.4	1.5	6.0	3.8	15.6	42.9	26.5
11	7.3	0.7	6.5	21.5	35.5	2.7	13.2	9.5	17.8	58.3	38.3
12	7.0	0.3	9.7	23.9	68.1	33.1	13.0	10.4	14.6	4.2	30.0
13	7.4	0.3	6.0	28.1	92.6	6.7	7.3	4.5	18.9	15.5	35.3
14	7.2	0.3	7.2	39.5	62.5	8.0	11.4	8.2	22.4	118.3	41.0
15	6.8	0.7	8.4	29.9	46.0	9.6	19.5	8.1	16.7	78.3	42.5
16	7.1	0.5	8.4	35.3	43.5	16.3	20.0	8.1	14.2	40.3	45.9
17	6.4	0.8	8.8	19.1	26.9	5.9	19.7	6.8	11.8	15.5	32.8
18	7.0	0.6	10	38.3	73.0	5.4	19.5	10.6	19.7	364.2	45.3
19	7.5	0.4	6.7	19.1	69.9	3.4	13.6	10.9	12.3	10.3	39.8
20	7.5	0.9	9.3	34.1	39.2	17.0	40.2	3.3	21.8	167.6	35.3
21	7.6	0.1	6.3	20.7	16.9	4.7	5.6	4.4	12.4	20.1	50.2*

EC= Electric conductivity; OM= Organic matter; CEC= Cation Exchange Capacity; Ca= Calcium; Mg= Magnesium; Na= Sodium; K= Potassium; N= Nitrogen; P= Phosphorus * average value of oil content.

al. (2021) obtained values of 28.09 cmol kg^{-1} in a Vertisol from the South of Indonesia.

In terms of exchangeable cations, Ca showed an average value of 38.6 cmol kg^{-1}. The minimum and maximum values were 7.4 and 92.6 cmol kg^{-1}, respectively. The results obtained from the 21 sites analyzed indicated that 95% presented high amounts of Ca according to the NOM-021-SEMARNAT-2000. Luna et al. (2012) obtained values between 7.8 cmol kg^{-1} and 17.3 cmol kg^{-1}. However, another study conducted by Adegbite et al. (2020) reported lower values (from 1.6 cmol kg^{-1} to 4.5 cmol kg^{-1}) in an Alfisol.

Magnesium ion concentrations varied considerably, ranging from 0.60 cmol kg^{-1} to 33.10 cmol kg^{-1}. Fifteen of the accessions exhibited high Mg contents, ranging from 3.4 to 33.1 cmol kg^{-1}, while six had intermediate (1.5 to 2.7 cmol kg^{-1}) and low concentrations (0.60 to 1.08 cmol kg^{-1}) according to the NOM-021-SEMARNAT-2000 standard. In this respect, Pierre et al. (2018) and Susilowati et al. (2021) reported high Mg values of 3.5 cmol kg^{-1} and 2.5 cmol kg^{-1} in Vertisols in Central Africa and Indonesia, respectively. Furthermore, Luna et al. (2012) reported values between 3.45 and 7.9 cmol kg^{-1} in soils of Querétaro, which were close to those found in the present study. Finally, data from accessions 12 (33.1 cmol kg^{-1}) and 16 (16.3 cmol kg^{-1}) differed from the values obtained in the abovementioned studies.

K ion content reached an average value of 6.9 cmol kg^{-1}, which is considered as high according to the NOM-021-SEMARNAT-2000 standard. Values ranged from 2.6 to 10.9 cmol kg^{-1} among the 21 accessions. Pierre et al. (2018) reported K concentrations of 0.16 cmol kg^{-1} in Vertisols in Central Africa, while Páez et al. (2016) found values of 0.3 cmol kg^{-1} in soils of Granada, Spain. Furthermore, Luna et al. (2012) have also reported high K^+ concentrations ranging from 0.53 to1.64 cmol kg^{-1}.

Na content ranged from 5.4 to 40.2 cmol kg^{-1}, with an average of 13.4 cmol kg^{-1}. Much lower values of 0.4 cmol kg^{-1} (Pierre et al., 2018) and, 0.8 cmol kg^{-1} (Susilowati et al.,2021) have been reported in Vertisols. Additionally, similar values ranging from 0.04 cmol kg^{-1} to 0.07 cmol kg^{-1} were found in an Alfisol (Adegbite et al., 2020). However, Luna et al. (2012) reported concentrations between 0.6 and 1.2 cmol kg^{-1}.

Inorganic N reached an average value of 16.32 mg kg^{-1}, varying between 11.8 and 22.5 mg kg^{-1}. In this sense, 85% of the soils had lower concentrations that ranged from 11.8 to 19.7 mg kg^{-1}; while the remaining 15% showed higher levels of 22.5 mg kg^{-1}, 22.4 mg kg^{-1} and 21.8 mg kg^{-1} for accessions 1, 14 and 20, respectively. Luna et al. (2012) found very low levels of inorganic N (between 0.004 and 0.017 mg kg^{-1}) in La Cañada, Querétaro, indicating that the soils show low to intermediate amounts of inorganic N.

Regarding available P, the average value was of 54.0 mg kg^{-1}, with minimum and maximum values of 4.2 and 364.2 mg kg^{-1} approximately. Based on the NOM-021-SEMARNAT-2000 standard, 18 accessions showed high P contents, recording values higher than 11 mg kg^{-1}; 2 accessions showed intermediate values (5.8 and 10.3 mg kg^{-1}); and only 1 presented low P levels (4.2 mg kg^{-1} for accession 12). The values obtained are in the range of those reported in previous studies, except for accession 14, 15, 18 and 20 (118.3, 78.3, 364.2, 167.6 mg kg^{-1}, respectively. In this sense, Zanor et al. (2019) reported values between 5.77 and 36.7 mg kg^{-1}, while Luna et al. (2012) reported P values between 4.5 and 51.4 mg kg^{-1} in Vertisols.

Overall, soils of El Marqués presented organic matter contents of 3.9 to 10%, cation exchange capacity that can be classified as intermediate (16.1 to 23.9 cmol kg^{-1}) and high (25.1 to 43.1 cmol kg^{-1}), and pH values between 6.4 and 8.3. The soils showed no salinity effects, high contents of exchangeable cations and available P (4.2 to 364.2 mg kg^{-1}), and low inorganic N contents (11.8 to 22.5 mg kg^{-1}).

Castor oil

Castor oil content recorded an average value of 38.5%. Castor bean seeds reached oil contents above 46% in 2 of the 21 accessions; 41 to 45% in 7 accessions; 36 to 40% in 5 accessions; 31 to 35% in 5 accessions; and 25 to 30% in 2 accessions. A study conducted by Palomino et al. (2011) reported that castor bean plants grown in Colombia produced seeds containing 50% castor oil, while another study in the same country revealed different content levels (%) in four varieties of castor bean: 31.7% for 'Blanca Jaspeada', 32.1% for 'Valle', 33.7% for 'Negra', and 36.1% for 'Violeta' (Hurtado-Salazar et al., 2013).

Goytia-Jiménez et al. (2011) reported oil contents between 12.2 and 64.84% in seeds of castor bean plants (151 sampled from different locations in Chiapas, Mexico). Furthermore, Ramos-López et al. (2012) obtained 37.31% seed oil from plants grown in Ecatepec, Mexico. These results agree with the average value obtained in our study (38.5%), indicating that El Marqués could be considered as a good place for producing castor oil, being La Cruz, Carretera Campus Amazcala and Juzgado Especializado the localities with the highest potential to grow castor bean plants for oil production.

Salicylic acid elicitation

The oil produced by castor bean seeds improved as the concentration of salicylic acid increased, which shows a positive correlation R^2 of 0.9487 (Fig. 1). This means that elicitation with SA has a beneficial effect on the production of this oil. On the other hand, the oil content in seeds of castor bean plants without elicitation ranged from 27.7% to 44.0% of the total seed-oil, with an average of 38.5%. The highest castor oil

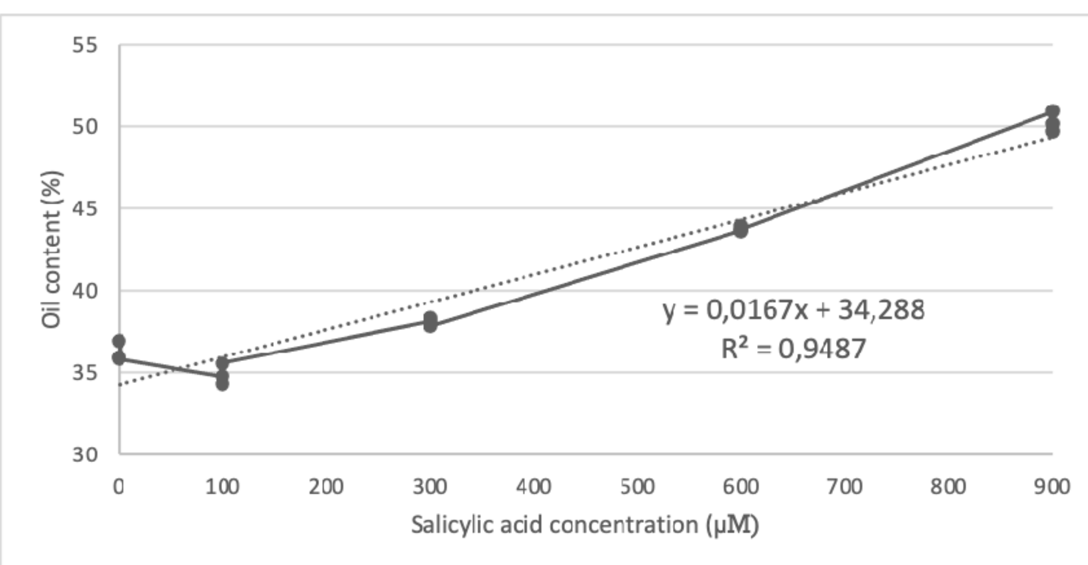

Fig. 1. Oil content of castor bean seeds from plants elicitated with salicylic acid.

content was registered in the plants elicitated with a concentration of 900 μM of SA, ranging from 48.7 % to 52.9%, with an average value of 50.2% (Table 4). Variations in oil content between the treatments reached 14%. This indicates that the elicitation process with SA was an effective technique to increase oil content in castor bean plants.

In terms of oil content, authors such as Gorni et al. (2020) and Alvarenga et al. (2022) have reported increases of 47 and 39% in *Achillea millefolium* L. and *Ocimum gratissimum* L., respectively, when applying concentrations of salycilic acid of 1.0 mM and 1.5 mM.

Table 4. Average oil content in castor bean plants elicitated with salicylic acid (%).

Treatment	Oil content (%)
900 μM	50.23±1.55 a
600 μM	43.75±2.36 b
300 μM	38.11±0.78 c
100 μM	34.89±5.98 c
0 μM	36.23±4.17 c

Average oil content was estimated using 3 measurements. Different letters indicate statistical differences by Tukey test (p=0.05).

CONCLUSIONS

Elicitation with salicylic acid is an effective method to increase the concentration of oil content in castor bean seeds. El Marqués has good potential for the cultivation of castor bean plant and production of castor oil.

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