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Original Paper

MORPHOBIOMETRIC CHARACTERISATION OF CAROB TREE PODS CULTIVATED IN ALGERIA AND EVALUATION OF PHYSICOCHEMICAL, NUTRITIONAL, AND SENSORY PROPERTIES OF THEIR POWDERS

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Given its very important economic and environmental interests, the cultivation of carob tree in Algeria has experienced remarkable development, which is reflected in the methods of plant multiplication, the increase in the surface area of its cultivation, and in particular, the growing number of carob fruit processing industries (first and second transformation). In this context, the present study focused on the evaluation of the food quality of whole pod powders and carob pulps from three different regions of Algeria (Boumerdes, Relizane, and Tissemsilt). The experimental part presents a morphobiometric characterisation of carob pods carried out during the 2020–2021 production campaign — length, width, mass, volume, thickness, size index (length/width), the number and mass of seeds, analysis of the food quality of carob powders from whole pods and their pulps and determining their physicochemical properties (particle size, pH and dry matter), nutritional properties (ash, crude proteins, total sugars, crude fibres, fats) and sensory (colour, taste, texture, and smell). The results showed that the morphobiometric characteristics of the carob pods studied (physicochemical, nutritional, and sensory properties of the powders) strongly depend on the biogeographical site of the carob tree and the conditions of its production. Compared to the other carob fruit powders analysed, Relizane carob pulps powder showed a better sensory appreciation; this powder was characterised by a colour (100% light brown), taste (50% sweet, 50% very sweet), texture (100% fine), and odour (100% carob with strong intensity). Indeed, the study of the food quality of the two types of powders obtained separately from whole pods (seeds and pulps) and from the pulps is very valuable and opens possible ways of food valorisation of carob tree fruit.

Keywords: *carob fruit, pulp, seed, food quality, valorisation.*

INTRODUCTION

Carob tree (*Ceratonia siliqua* L.) is an evergreen xerophyte tree of the *Leguminosae* family, native to the arid and semi-arid Mediterranean region (also found in Africa and Latin America), which produces large pods with several seeds (Ozcan *et al.*, 2007; FAO, 2018; Papaefstathiou *et al.*, 2018). The ancient Greeks brought it to Greece and Italy, while the Arabs spread it across the North African coast, Portugal, and Spain (Batlle and Tous, 1997). It is widespread almost all around the world (Spain, Italy, Morocco, Greece, Cyprus, Turkey, Australia, South Africa, California, and Arizona) (Issaoui *et al.*, 2021).

The latest research by the Food and Agriculture Organisation exposes that carob fruit is worldly produced at the rate of 158.609 tons per year, derived from 66.874 hectares, where the contribution from Asia, Europe, and Africa is 11.3%, 75.55%, and 13%, respectively (Pernet and Ribi Forclaz, 2019).

The Mediterranean basin is the main carob production centre, with annual production of more than 135.000 tons (FAO, 2019). Carob is perhaps the most representative plant for agro-forest ecosystems for the Mediterranean region (Ikram *et al.*, 2023; Tzatzani and Ouzounidou, 2023). Carob tree has several advantages; it combines the attributes of a forest, an ornamental, and an orchard tree, while producing fruits for human and for animal consumption. As a forest tree it can stop erosion and modify the appearance of areas (Correia and Pestana, 2018), it is also resistant to fires, and can exploit relatively barren soils that are unsuitable for other crops, while preserving their fertility and protect them from erosion.

Additionally, carob tree is an excellent decorative plant for private and public gardens, parking areas, and sidewalks, making places more attractive and healthier, as it absorbs 15.56 t CO_2 eq/ha/y (Correia and Pestana, 2018).

Moreover, the food processing of carob pods does not generate waste, while opening up new opportunities to explore land resources in cities to produce food, in line with educated suggestions from some researchers (Vanham *et al.*, 2016; Lal, 2020; Rippin *et al.*, 2020). In fact, carob products (flour, powder, and syrup) are traditional Mediterranean foods recently recognised by UNESCO and included in the Greek and Cyprus National Catalog of Intangible Cultural Heritage (Tzatzani and Ouzounidou, 2023).

The Mediterranean is the place where carob originated and is expected to play an important role in the cultivation of carob in the coming years (Tzatzani and Ouzounidou, 2023). Until recently, the cultivation of carob was by extensive farming, but during the last 20–30 years, several systematic farms have been introduced, and production relies less on grafted wild plants and more on organised farming systems to increase yield, which depends on the cultivar and regional and cultural practices (Makris and Kefalas, 2004). Propagation is now done by grafting on seedlings (Tzatzani and Michail, 2022; Tzatzani and Ouzounidou, 2023).

According to Durazzo *et al.* (2014), the carob pod consists of pulp (90%) and seed (10%). Depending on the genotype, there are wild and cultivated carob species, which are distinguished by their seeds and pulp (Yousif and Alghzawi, 2000). The pulp is rich with sugars (48–56%, mainly sucrose) and contains about 16–20% tannin (Biner *et al.*, 2007). Cultivated carob has a higher amount of total soluble sugars than the wild species (Albanell *et al.*,1991).

Carob can be used as a natural ingredient for producing fresh and nutritious foods, depended on the manufacturing process, and results of clinical trials show that carob can treat different diseases including hyperlipidemia, diabetes, colorectal cancer, and irritable bowel syndrome Ikram *et al.* (2023).

In most cases, pulp is assumed to be a by-product (Fidan *et al.*, 2019). The seeds are considered to be the most valuable part of the fruit because the polysaccharide is widely used in the food industry (Youssef *et al.*, 2013; Bulca, 2016). Carob (the pulp and its seeds) is used for the production of flour, extract, especially concentrated syrup form pulp (Turhan *et al.*, 2010) and locust bean gum (Batu, 2005; Ayaz *et al.*, 2009).

In addition, carob, unlike cocoa, is richer in nutrient properties, is less caloric, contains no psychoactive substances, is rich in vitamins (riboflavin) and minerals (calcium, potassium, copper, and manganese), helps metabolic functions, and supports the nervous system, and therefore it represents a valid substitute for traditional chocolate, especially in categories of people such as athletes, children, and pregnant women and, last but not least, it is appropriate for people with celiac disease, because it is gluten-free in contrast to cocoa (Lanfranchi *et al.*, 2019).

According to Roseiro *et al.* (2013), pods and seeds of carob fruit can be used as raw material in food, pharmaceutical, and cosmetics industries. In the food industry, they are used in preparing gum, sugars, alcohol, and as a natural additive (E 410) (Durazzo *et al.*, 2014).

Also due to its sweetness, flavour similar to chocolate, and its low price, the seedless pod’s powder is widely used in the Mediterranean region as a cocoa substitute for sweets, biscuits, confectionery products, bakery goods and drink production (Ayaz *et al.*, 2007; Durazzo *et al.*, 2014). One of the advantages of using carob powder as a cocoa substitute is that it is free from caffeine and theobromine (Biner *et al.*, 2007; Bengoechea *et al.*, 2008; Durazzo *et al.*, 2014).

Carob is mainly used in Arab countries to prepare a drink and partially some types of confectioneries; in Western countries, carob powder is prepared by deseeding pods to yield kibbled carob, then heating, milling, sieving, and packaging (Ibrahim *et al.*, 2020). These powders can be used to prepare carob juice concentrate (Owen *et al.*, 2003).

Research has been carried out on the effect of enhancing some food products with carob pod powder, such as pasta (Biernacka *et al.*, 2017), muffins (Cervenka *et al.*, 2019), or alcoholic beverages (Rodríguez-Solana *et al.*, 2019). Carob pod powder is usually prepared by drying, subsequently milling, and roasting, which ensures a high phenolic content and desired sensory properties (Gunel *et al.*, 2020).

Carob has been eaten as a cheap source of human and animal nutrition for years due to its different properties (Ramón-Laca and Mabberley, 2004). The carob market has been growing in recent years, and is expected to grow even more up to 2027 (Tzatzani and Ouzounidou, 2023).

Algeria was classified ninth rank as a carob producer in the world by its average production of 3.577 tons per year (FAOSTAT, 2021). Given the marketable quality of carob powder at the international level, the industry of first processing of carob has been established in Algeria with a growing cultivation of carob tree encouraged by the sector concerned.

There is abundant literature on wild and cultivated carob tree regarding their in their biodiversity, valorisation and economic aspects (Ayaz *et al*., 2007; Mahtout *et al*., 2018; Habibzadeh and Seyedain Ardabili, 2019; Fidan *et al*., 2019; 2020; Gadoum *et al*., 2021; Brassesco *et al*., 2021; Darwish *et al*., 2021; Mahdad *et al*., 2022; Caliskan *et al*., 2022; Gioxari *et al*., 2022; Arab *et al*., 2022; Lupu *et al*., 2023). On the other hand, in Algeria little work has been carried out and published on the variability of the food quality of carob powder depending on the biogeographical site of the carob tree. In this context, the present work mainly aims to highlight the impact of some biogeographical sites in Algeria on the morphology of carob fruits and on some components of the food quality of their powder, in order to facilitate the establishment of specific local standards concerning its physicochemical and nutritional quality.

MATERIALS AND METHODS

Carob pods. In 2021 (late August and September), ripe carob pods were collected manually from three different biogeographical sites in Algeria: Wilaya of Boumerdes (commune of Thyzza: latitude 36.637573°, longitude 3. 566027°, altitude 102 m), Wilaya of Relizane (commune of Ouled Meziane: latitude 36.112046°, longitude 0.856769°, altitude 375 m),and Wilaya of Tissemsilt (commune of Melaab: latitude 35.714488°, longitude 1.332521°, altitude 947 m).

In the laboratory, the carob pods were sorted and cleaned of dust by wiping them with a sterile absorbent paper, and then they were wrapped in aluminium foil and kept in perfectly aseptic in sterile plastic food boxes (22 litre capacity) and stored in ambient temperature and away from light.

Preparation of carob powder. For each collection site, after a second dusting of the pods, if necessary with sterile absorbent paper, the pulps were manually separated from the pods and the seeds were saved for later use.

Two types of powder were produced, one from the whole pods (pulps and seeds) and one from the pulps. The two fresh crude materials (whole pods and pulps) were crushed separately and completely (100% extraction rate) by using a grinder (BOMANN brand, Germany) set at 28,000 rpm for 3 minutes.

The six powder samples were aseptically coated with aluminium foil and placed in sterile lunch boxes and stored aseptically at room temperature and away from light.

Characterisation of carob pods. The morphobiometric characteristics of carob pods were determined according to a previous study (Haddarah *et al*., 2013); ten pods of each carob variety were randomly selected to measure their different parameters: length, width, mass, volume, thickness, size index (length/width), and number and mass of seeds.

Characterisation of carob powders

Physicochemical characterisation. The physicochemical parameters analysed for the six carob variety powder samples were: granulometry of the carob powders determined by the sieve analysis method (AACC, 1999), pH value by pH meter method (AOAC, 1995) and dry matter content by AOAC (1990).

Nutritional characterisation. For the nutritional characterisation of different carob variety powders, we analysed the following parameters: ash (AOAC, 2000), crude protein (Kjeldahl, 1883), total sugars (Dubois *et al*., 1956), crude fibre by Weende method (Henneberg and Stohmann, 1860) and fat content by ISO (659, 2009).

Sensory characterisation. The sensory quality of carob fruit powders was assessed using a hedonic and descriptive approach. The sensorial analysis of carob powders for the three biogeographical sites of Algeria (Tissemsilt, Boumerdes, and Relizane) was determined by evaluation of the overall acceptability of the six carob powders: two types of carob powders (pods and pulps powders) in three biogeographical sites. The overall acceptability of carob powders was evaluated by considering two profiles: visual and taste (Seczyk *et al.,* 2016). The visual profile included attributes such as colour and overall acceptability, and the taste profile included taste, texture and smell.

For performing the analysis, a 6-point hedonic scale was used. Each scale corresponded to a perception in order to facilitate data processing as follows: 0: unpleasant, 1: little unpleasant, 2: neither unpleasant nor pleasant, 3: not very pleasant, 4: pleasant and 5: very pleasant.

For descriptive analysis, descriptors were chosen to evaluate the visual and taste profile of the different carob fruit powders. The used descriptors were: colour (brown, light brown, dark brown, yellow, light yellow, and dark yellow), taste (bitter, slightly sweet, sweet, very sweet, and acid), smell (carob with low intensity and carob with strong intensity), and texture (fine and coarse).

Sensory analysis was performed at the Faculty of Nature Sciences and Life, Department of Nutrition and Agro-food technology, University of Tiaret, Algeria. The panel of tasters was composed of ten healthy adults aged 20–30 years and qualified to evaluate the sensory properties of foods. The participants in the study were persons with experience and competencies in sensory analysis, including teachers and students who have studied and taught the mentioned subject. The panellists were asked to evaluate each sample for the assessed parameters. Panellists received the samples by turn in order to diminish the similarity and interdependence between samples, with a 5 min rest before each sample tasting.

The six powder samples were coded and presented in disposable plastic plate to the tasters in a lit room and the analysis was carried out between 1 and 4 hours after breakfast in an ambient temperature around 20 °C (+/– 3 °C).

Before and after each analysis, the panellists rinsed their mouths with drinking water (mineral water) and they inhaled a coffee powder presented on a disposable plastic plate. Consent of each panellist was required.

We statistically compared the mean (average) values of the parameters using R software.

RESULTS

Carob pods

Morphobiometric characterisation. Table 1 provides average morphobiometric characteristics of carob pods.

The study of the morphobiometric parameters of carob pods from three sites showed that the means found for all the parameters were similar between sites: length (Boumerdes pods 12.54 cm, Tissemsilt pods 12.23 cm, Relizane pods 11.79 cm, width (Boumerdes pods 1.34 cm, Tissemsilt pods 1.45 cm Relizane pods 1.18 cm), thickness (Boumerdes pods 0.70 cm, Tissemsilt pods 0.62 cm, Relizane pods 0.43 cm), size index (Boumerdes pods 9.35, Tissemsilt pods 8.43, Relizane pods 9.99), number of seeds (Boumerdes pods 9.8, Tissemsilt pods 8.5, Relizane pods 7.4) and seed mass (Boumerdes pods 1.6 g, Tissemsilt pods 1.43 g, Relizane pods 1.38 g).

Two parameters significantly differed between sites: volume of pods (Boumerdes pods 15.5 ml, Tissemsilt pods 10.8 ml, Relizane pods 9.1 ml) and mass of pods (Boumerdes pods 15.59 g, Tissemsilt pods 12.24 g, Relizane pods 9.22 g).

Carob powder

Physicochemical characterisation

Granulometry

The granulometric composition of carob powder is given in Table 1:

-250 µm sieve Boumerdes (pods 19.11%, pulp 22.45%); Relizane (pods 23.01%, pulp 21.72%); Tissemsilt (Pods 27.95%, pulp 17.84%).

-500 µm sieve Boumerdes (pods 7.17%, pulp 8.26%); Relizane (pods 12.25%, pulp 5.67%); Tissemsilt (pods 11.4%, pulp 7.29%).

-1000 µm sieve Boumerdes (pods 2.84%, pulps 0.31%); Relizane (pods 7.45%, pulp 2.2%); Tissemsilt (pods 6.73%, pulp 0.67%).

pH

Table 1 shows the mean pH values of carob powder. For the six carob powders analysed, the mean pH values were simi-

Table 1. Mean values of carob pods morphobiometry and physicochemical and nutritional characteristics of their powders

Carob pods			
Carob pods morphobiometry	Biogeographical sites		
	Boumerdes	Relizane	Tissemsilt
Pods length (cm)	12.54	11.79	12.23
Pods width (cm)	1.34	1.18	1.45
Pods thickness (cm)	0.7	0.43	0.62
Pods size index	9.35	9.99	8.43
Pods seeds number	9.8	7.4	8.5
Pods seeds mass (g)	1.6	1.38	1.43
Pods volume (ml)	15.5	10.8	9.1
Pods masse (g)	15.59	12.24	9.22

Carob powders						
Physicochemical and nutritional characteristics	Boumerdes		Relizane		Tissemsilt	
Granulometry (%)	pods	pulps	pods	pulps	pods	pulps
250 µm	19.11	22.45	23.01	21.72	27.95	17.84
500 µm	7.17	8.26	12.25	5.67	11.4	7.29
1000 µm	2.84	0.31	7.45	2.2	6.73	0.67
pH	4.94	4.92	4.6	4.71	4.93	4.81
Dry matter (%)	89	90.3	91.2	90.15	87.06	72.31
Ash (%)	4.12	3.7	3.22	3.32	3.21	3.36
Crude protein (%)	31.32	8.31	38,85	10,85	42,87	10,5
Total sugar (%)	15.61	38.26	9.48	24.48	10.1	12.55
Crude fibre (%)	11.6	10.5	10.3	9.12	12.06	10
Fat (%)	1.53	1.7	3.31	1.22	1.38	2.85

lar to each other and acidic Boumerdes (pods 4.94, pulp 4.92); Relizane (pods 4.60, pulp 4.71); Tissemsilt (pods 4.93, pulp 4.81).

Dry matter

Mean dry matter content of carob powder is presented in Table 1. The mean dry matter for the various powders of the carobs were similar between Boumerdes (pods 89%; pulp 90.3%) and Relizane (pods 91.2%, pulp 90.15%), while being lower for pulp in the Tissemsilt site (pods: 87.06%, pulp 72.31%).

<u>Nutritional characterisation</u>

Ash

Table 1 shows mean ash content of the carob powder.

The ash content was lower for the Tissemsilt pulp powder and highest in the Boumerdes site: Boumerdes pod powder (pods 4.12%, pulp 3.7%); Relizane (pods 3.22%, pulp 3.32%); Tissemsilt (pods 3.21%, pulp 2.36%) .

Crude protein

Table 1 gives the mean crude protein content of the carob powder. Table 1 shows that the carob pod powder had higher mean crude protein content than those found in carob pulp powder: Boumerdes (pods 31.32%, pulp 8.31%); Relizane (pods 38.85%, pulp 10.85%); Tissemsilt (pods 42.87%; pulp 10.50%).

Total sugar

Mean total sugar content of carob powder is shown in Table 1. In contrast to the results found for total sugar, carob pulp powder had higher mean total sugar content than in carob pod powder: Boumerdes (pods 15.61%, pulp 38.26%); Relizane (pods 9.48%, pulp 24.48%); Tissemsilt (pods 10.1%; pulp 12.55%) .

Crude fibre

Table 1 represents the mean crude fibre content of carob powder. The mean content of the crude fibres found in carob pods powder was slightly higher than in the carob pulp powder: Boumerdes (pods 11.6%, pulp 10.5%); Relizane (pods 10.3%, pulp 9.12%); Tissemsilt (pods 12.06%; pulp 10%).

Fat

Mean fat content of carob powder is shown in Table 1. Lower mean fat content occurred in powder of pulp from Relizane and the highest in powder of pods of Relizane: Boumerdes (pods 1.53%, pulp 1.7%); Relizane (pods 3.31%, pulp 1.22%); Tissemsilt (pods 1.38%; pulp 2.85%).

<u>Sensory characterisation.</u> Figure 1 illustrates the sensory characteristics in terms of overall acceptability, colour, taste, texture, and smell of carob powder of the three biogeographical sites.

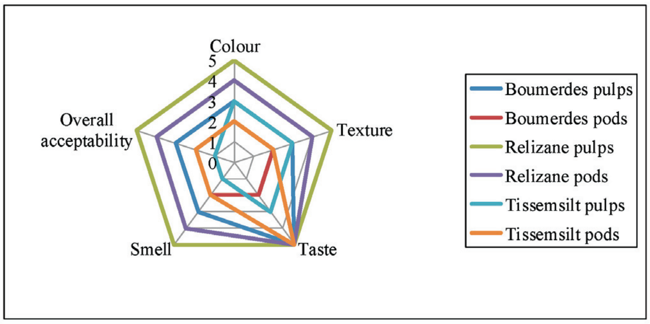

Fig. 1. Overall acceptability, colour, taste, texture and smell of carob fruit powders of three biogeographical sites.

According to Figure 1, Relizane pulp powder was the most preferred by the panellists in terms of general acceptability, colour, taste, texture, and odour. Relizane pulp powder was ranked first with a mean score of 5 compared to the other carob powders studied: Relizane pods (second place with an mean score of 4), Boumerdes pulp (third place with a mean score of 3), Tissemssilt pods (fourth place with a mean score of 2), Boumerdes pods (fifth place with a mean score of 2) and Tissemssilt pulp (sixth place with a mean score of 1).

The results of evaluation of the descriptive sensory analysis of carob powders were as follows: Relizane pulp powder — colour (100% light brown), taste (50% sweet, 50% very sweet), texture (100% fine) and odour (100% carob with strong intensity); Relizane pod powder — colour (100% light brown), taste (90% sweet, 1% slightly sweet), texture (70% fine, 30% coarse) and odour (100% carob with strong intensity);

Boumerdes pulp powder — colour (100% dark brown), taste (20% sweet, 30% slightly sweet, 20% very sweet, 30% acid), texture (100% coarse) and odour (100% carob with low intensity); Boumerdes pod powder — colour (100% dark brown), taste (30% bitter, 40% sweet, 30% slightly sweet), texture (100% fine) and odour (100% carob with low intensity);

Tissemsilt pulp powder — colour (100% yellow), taste (50% sweet, 50% acid), texture (100% fine) and odour (100% carob with low intensity); Tissemsilt pods powder — colour (100% yellow), taste (80% sweet, 10% very sweet, 10% acid), texture (70% fine, 30% coarse) and odour (100% carob with low intensity).

DISCUSSION

These results are comparable to those found respectively by Kocherane *et al*. (2019), Gadoum *et al.* (2021) and Mahdad *et al*. (2022) for the following average morphobiometric parameters: pod length (15.27 cm; 14.30 cm; 15.05 cm), pod width (1.97 cm;1.69 cm; 2.13 cm), pod thickness (0.76 cm; 0.58 cm; 0.63 cm), number of seeds (10.56; 9.98; 10.97) and mass of pods (11.08 g; 8.36 g; 15.17 g). These findings are strongly linked to the growing conditions (soil, climate), biogeographical site of the crop and to the genetic diversity of the plant (Tzatzani and Ouzounidou, 2023).

The pods vary significantly in morphological characteristics such as dimension, size, weight, shape, density, colour, and seed-to-pulp ratio due to differences in cultivar varieties, climate conditions and farming practices (Tous *et al*., 2013; Benchikh *et al*., 2014; Nasar-Abbas *et al*., 2016). Carob can survive in very precarious conditions; its rich root system retains and protects the soil from erosion. It is well adapted to marginal soils, both calcareous and rocky, and low rainfall (Correia and Pestana, 2018).

The results of a study on morphometric and physicochemical characteristics of carob pods in three geographical regions of Morocco (Fadel *et al*., 2020) showed that environmental factors seem to have an important effect on the morphometric characters of pods and seeds; for example, the environment in the northern exposure and rain appeared to improve the mass, length, width and thickness of the pods compared with other regions such as the centre and southwest, they also promoted the mass of seeds per pod, mass of the pulp, peduncle length, width, length and thickness of the seeds. The increase in mass of the pulp and the seeds of carob tree in the localities with heavy rain could increase the commercial value of the fruit (Fadel *et al.*, 2020).

The particle size of the carob powders can be modified by pre-treatment applied to the carob (pods and pulps) on the one hand, as well as the technique and the operating conditions of grinding on the other hand. Commercial producers use mechanical milling devices and high temperature drying ovens to turn the carob pulp into powder. In contrast, small-scale domestic producers sun-dry the carob kibbles for several weeks in the open air, then grind them to a fine flour with stone or wooden mortar and pestle, and finally store the dry product in cloth bags, glass jars, ceramic bowls, or metal containers (Ayaz *et al*., 2009).

In Western countries, carob powder is produced by deseeding of carob pods, yielding of kibbled carob, followed by roasting and milling of the kibbled carob. The produced carob powder is sold in USA and other Western countries in health food stores as a substitute or extender for cocoa (Yousif and Alghzawi, 2000).

According to a study by Yousif and Alghzawi (2000), the pH value of carob powder depends on its native composition and its pretreatment (roasting) before the grinding operation; they found that the pH value (4.81) of roasted carob powder was lower than obtained for non-roasted carob powder (5.96), and higher than for carob powder (pods and pulps).

Because the enzymatic browning (caramelisation) occurs during the roasting process, the formation of by-products and other intermediates, such as pyruvic acid, might be expected (Lee *et al*., 1990).

The pH values in our study were strongly similar to those found by Tounsi *et al*., (2022): pH = 5.10 for pods carob powder as a co-product prepared after molasses production and pH = 5.61 for cacao powder. Thus, prepared carob powders are characterised by acid pH, which might contribute to long-term preservation and provide excellent protection against all bacteria and fungi (Jridi *et al*., 2015).

According to the literature, the moisture content in carob pods ranges between 3.6–18.0 $g \cdot 100\ g^{-1}$ (Würsch *et al*., 1984; Marakis, 1996; Battle and Tous, 1997). Our results are similar to those obtained by Mahtout *et al*. (2018), who found: 9.5% moisture for pods and 8.4% moisture for pulps. Pod carob powder as a co-product prepared after molasses production also had similar moisture contents (Tounsi *et al*., 2022): pod carob powder (8.01% moisture) versus cacao powder (7.715% moisture).

Moisture content is the most fundamental and important parameter of a food product; the dry matter that remains after moisture removal is commonly referred to as total solids (Nielsen, 2010). Water is an inexpensive filler, and therefore its removal from dry food materials increases convenience during packaging and transportation (Nielsen, 2003). According to Nielsen (2010), moisture (or solids) content is often specified in compositional standards (i.e. Standards of Identity). The moisture content of raw food materials has a remarkable effect on the operational properties and thus on the choice of determination technique and equipment to be used during processing, as well as on quality of both raw materials and final products (Charley, 1982; Nielsen, 2003). However, moisture removal from food products might causer destruction of other important food components. For example, at elevated temperatures, the amino acid and sugar contents may be reduced (probably because of caramelisation and the Millard reaction during roasting), proteins may be denatured, and vitamins and volatile components might be lost (Nielsen, 2003).

According to Batlle and Tous (1997), besides species differences and other environmental factors such as climatic conditions at harvest, the moisture content of carob pods is also dependent on factors such as the ripening status and relative atmospheric humidity**.** When still in a fresh state, pods generally have moisture content between 10 and 20% (Batlle and Tous, 1997). Drying to a moisture content below 10% is necessary to avoid rotting of the pods during storage prior to processing (Batlle and Tous, 1997; Curtis and Race, 1998). Determination of the nutritional value of foods requires that the moisture content must be known (Nielsen, 2003).

The estimated values for ash content are similar to those obtained previously (Mahtout *et al*., 2018): 2.6% ash for pods and 3% ash for pulps of carob, and also for pods carob powder as a co-product prepared after molasses production (Tounsi *et al*., 2022): pods carob powder (2.41% minerals) versus cacao powder (6.66% minerals). Carob ash content normally ranges between 1 and 6 $g \cdot 100\ g^{-1}$ (Calixto and Cańellas, 1982; Bravo *et al.,* 1994; Avallone *et al*., 1997; Yousif and Alghzawi, 2000).

Deficiencies of minerals in human nutrition have characteristic effects, which can result in an abundant incidence of common disorders and disease symptoms (Cole and Kramer, 2016; Gharibzahedi and Jafari, 2017). Cocoa beans and carob pulp are very rich sources of many essential minerals (Loullis and Pinakoulaki, 2018); among the major micronutrients, cocoa, and carob contain calcium, potassium, phosphorous, magnesium and sodium. Potassium is the predominant mineral in both cocoa and carob, while the concentration of calcium is considerably higher in carob (Andrea *et al*., 2000; Ayaz *et al*., 2007; Gubbuk *et al*., 2010; Sigge *et al*., 2011; Colombo *et al*., 2012). The concentration of calcium in carob is so high (~ up to 480 mg/100 g) that can be compared to calcium intake from a cup of cow milk (Singh *et al*., 2007). The micro-minerals present in cocoa and carob are iron, copper, manganese and zinc, with iron being predominant (Andrea *et al*., 2000; Ayaz *et al*., 2007; Gubbuk *et al*., 2010; Sigge *et al*., 2011; Colombo *et al*., 2012).

The observed crude protein content values were higher than those obtained by Mahtout *et al*., 2018), who reported 4% crude protein for pods and 3% crude protein for pulp, and also for pod carob powder as a co-product prepared after molasses production (Tounsi *et al*., 2022): pod carob powder (6.68% crude protein) versus cacao powder(21.52% crude protein). Carob protein content ranges between 1.0 and 7.6 $g \cdot 100\ g^{-1}$ depending on cultivar differences, origin and farming practices (Calixto and Cańellas, 1982; Owen *et al*., 2003).

Other study showed that cocoa is rich in proteins, while carob contains lower amounts; proteins constitute 10–16% of cocoa beans and contains albumins (water soluble), globulins (salt soluble), glutelins (soluble in dilute acids and alkali) and prolamins (alcohol soluble) (Ayaz *et al*., 2007; Bertazzo *et al*., 2013). The protein fraction in carob pulp is lower than cocoa, ranging between 2 and 7% (Avallone *et al*.,1997; Nasar-Abbas *et al*., 2016); higher protein content reaching up to ~50% is found in the carob germ.

Our estimates of total sugar are lower than those obtained by Mahtout *et al*. (2018): 66.6% total sugar for pods and 65% total sugar for pulp. The carbohydrate content of carob pod content can be as high as 89 $g \cdot 100\ g^{-1}$, depending on variety, climate and other horticultural conditions (Biner *et al*., 2007). According to Biner *et al*. (2007) and Kumazawa *et al*. (2002), sugars contained in the pods are almost entirely sucrose, fructose and glucose. Of these three, sucrose accounts for up to 70%, with glucose and fructose sharing the remaining percentage in equal proportions (Zografakis and Dasenakis, 2000). Values of up to 95% sucrose (on total sugar basis) have also been reported (Bravo *et al.*, 1994). This identifies carob pods as a good sucrose source, even as an alternative to sugar beet and sugar cane. It is worth noting that the use of carob pulp in food, more specifically in confectioneries and other sweet-tasting products is mainly due to the high sugar (sucrose) content (Bravo *et al.*, 1994; Biner *et al.*, 2007). The ratios of individual sugars to the total sugar content are generally similar between cultivated and wild carob types (Bravo *et al*., 1994). Carob pulp has much higher sugar content, ranging from 40 to 55%, with sucrose, fructose and glucose being the dominant sugars (Avallone *et al*., 1997; Ayaz *et al*., 2007; Biner *et al*., 2007). The sugar content of carob pulp can vary considerably according to species, variety, physiological maturity, harvest season, climate and storage conditions (Ayaz *et al*., 2007). Furthermore, carob sugars are usually extracted from carob pulp for the production of natural carob syrup (Özcan *et al*., 2007).

Total fibre content values obtained in our study were lower than obtained by Tounsi *et al*. (2022): 56.49% total fibre for pod carob powder as a co-product of molasses and 50.73% total fibre for cacao powder. The dietary fibre content of carob pulp has been reported in the range of 7.6 and 38 % (Cavdarova and Makris, 2014; Aprotosoaie *et al*., 2016; Nasar-Abbas *et al*., 2016). Dietary fibre is a combination of chemically heterogeneous substances, which usually are categorised based on their solubility in water into insoluble and soluble dietary fibre (Loullis and Pinakoulaki, 2018). The insoluble fibres do not dissolve in hot water and they mainly consist of cellulose, hemicellulose and lignin, while soluble fibres, such as pentosan, pectins gums and mucilage are dissolved in hot water (Cui *et al*., 2011; Gao and Yue, 2012). Dietary fibre is one of the most important food ingredients used in nutritional and functional foods; the importance of dietary fiber in the food industry lies in the properties fibre can add to food, such as texture modifications and enhancement of the stability of the food during production and storage (Thebaudin *et al*.,1997; Cardador-Martínez *et al*., 2017). Dietary fibre has been shown to have several beneficial physiological effects such as improved intestinal function, cholesterol reduction and increased microbial mass (Loullis and Pinakoulaki, 2018). Other benefits include weight reduction, improved satiety, regulation of glucose and insulin responses and improved microbiota composition due to its fermentation in the large colon (Cui and Roberts, 2009; Cui *et al*., 2011).

Our values for crude fat were similar to those obtained by Mahtout *et al*. (2018): 2.4% crude fat for pods and 1.5% crude fat for pulp, and also to results for pod carob powder as a co-product prepared after molasses production (Tounsi *et al*., 2022): carob powder (0.58% crude fat) versus cacao powder(11.14% crude fat). Nutritional studies on carob have reported varying fat contents ranging between 0.2–2.3 $g.100\ g^{-1}$ (Avallone *et al.*, 1997; Yousif and Alghzawi, 2000; Biner *et al.*, 2007). In carob, the fat content is very low, ranging between 0.4 and 1.3% (Shawakfeh and Ereifej, 2005; Gubbuk *et al*., 2010; Sigge *et al*., 2011). Fat in carob is comprised of linoleic (C18:2n6) and linolenic (C18:3n3) polyunsaturated acids, oleic (C18:1n9) monounsaturated acid and palmitic (C16:0) and stearic (C18:0) saturated acids (Gubbuk *et al*., 2010; Sigge *et al*., 2011).

Due to the very low fat content, carob may be regarded as a healthier food source and can be an ideal ingredient for the production of low-fat products (Loullis and Pinakoulaki, 2018).

Carob powder processing can have very different effects on the nutritional composition (sugars, proteins, polyphenols, minerals and vitamins), and on sensory characteristics (taste, colour, and aroma) of the final carob product (Ayaz *et al*., 2009; Cepo *et al*., 2014).

These results can be linked to several factors, such as the nature of the raw material, its chemical composition and its geographical origin, the powder manufacturing process, etc.

Overall, the nutritional and economic advantages that carob presents make it a great candidate for the substitution of cocoa; the key in the potential of carob in substituting cocoa is the cocoa-like aroma and flavor that carob powder obtains after roasting (Loullis and Pinakoulaki, 2018).

Furthermore, carob pulp's similar sensorial, chemical and biological properties to cocoa, the absence of the stimulating alkaloids theobromine and caffeine, as well as its low-fat content, make it a healthier potential substitute for cocoa (Rodríguez-Solana *et al*., 2021).

According to the study by Rodríguez-Solana *et al*. (2021), carob products (e.g., syrups, beverages such as liqueurs and tea, pasta, bread, snacks, tahini, yogurt, etc.) appear to fulfil the modern health criteria of consumers (i.e. nutritional value, gluten-free, etc.), present adequate sensory characteristics (such as natural chocolate-like sweetness), and they can also be consumed by individuals allergic to cocoa compounds (caffeine- and theobromine-free). According to Tzatzani and Ouzounidou (2023), carob's natural sugars give a special taste to whichever product is added; it is now considered to be a super food, excellent for those who want a healthy diet and to improve their wellbeing.

The most abundant Volatile Organic Compounds of carob powder, fruits and flowers are propanoic acid, acetic acid, ethanol, furfural, which emit a sweet and buttery flavour, and a fruity, floral, woody, and almond flavour (Krokou *et al.*, 2018).

CONCLUSIONS

The comparative study of the morphobiometric parameters of the pods revealed that they vary according to their origin, of which those coming from the biogeographical site known as Boumerdes showed a volume and mass of the average pods greater than those noted in the two biogeographical sites studied (Tissemsilt and Relizane), and that the other average morphobiometric parameters recorded are similar between sites. The two types of carob fruit powders based on pulps and whole pods (pulps and seeds) have comparable physicochemical parameters — particle size, pH, and dry matter. Regarding the so-called nutritional parameters; the powder of carob based on the pods was rich in proteins in the three study sites (Boumerdes, Tissemssilt, and Relizane) of which the highest was recorded in Tissemsilt. On the other hand, the carob powder based on the pulps had a high in total sugar in the three study sites (Boumerdes, Tissemssilt, and Relizane), the highest of which in Boumerdes. In addition, the two types of carob powders are characterised by interesting and non-negligible contents of the parameters ash, fibre, fat for the different biogeographical sites.

Finally, the results of the present study can be used to construct the first database on the components of food quality of carob powders on the one hand, and provide possible ways of valorising the fruit of the carob tree cultivated in Algeria based on the variability of their morphobiometric, physicochemical and nutritional parameters of their powders (pulps and whole pods) in relation to their biogeographical sites.

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ALŽĪRIJĀ AUDZĒTO CERATONIJAS KOKA PĀKŠU MORFOBIOMETRISKIE RĀDĪTĀJI UN TO MILTU FIZIKĀLI ĶĪMISKO, PĀRTIKAS UN SENSORO ĪPAŠĪBU NOVĒRTĒJUMS

Rakstā salīdzinātas dažādos Alžīrijas reģionos audzēto ceratonijas (Jāņmaizītes koks) pākšu pazīmes un novērtēta no tām ar atšķirīgām metodēm pagatavoto miltu kvalitāte.