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Economic estimation of cactus pear production and its feasibility in Spain

Lucía Andreu-Coll [a], Marina Cano-Lamadrid [b], Luis Noguera-Artiaga [b], Leontina Lipan [b], Ángel A. Carbonell-Barrachina [b], Beatriz Rocamora-Montiel [d], Pilar Legua [a], Francisca Hernández [a], David López-Lluch [c,*]

[a] Department of Plant Science and Microbiology, Escuela Politécnica Superior de Orihuela (EPSO), Universidad Miguel Hernández de Elche (UMH). Ctra. Beniel, Km 3.2, 03312, Orihuela, Alicante, Spain
[b] Department of Agro-Food Technology, EPSO, UMH. Ctra. Beniel, Km 3.2, 03312, Orihuela, Alicante, Spain
[c] Department of Agroenviromental Economics, EPSO, UMH. Ctra. Beniel, Km 3.2, 03312, Orihuela, Alicante, Spain
[d] Department of Animal Production and Health, Public Health, Veterinary and Food Technology. Universidad Cardenal Herrera-CEU. C. Tirant Lo Blanc, 7. Alfara del Patriarca, Valencia, Spain

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ABSTRACT

This paper explores economic opportunities of *Opuntia* cultivation in Spain regarding fresh food production (comparing production structures of Mexico, Italy and Spain), cactus pear non-food uses (exploiting its bio-functional, medicinal, nutraceutical and cosmetic properties) and environmental issues related to climate change mitigation through soil carbon sequestration. Cactus pear production structures and costs are different in the three countries: Mexico (939.77 €), Italy (4.055.1 €) and Spain (9453.77 €). Spain does not present a real productive sector but only isolated farms. *Opuntia* is an interesting opportunity for non-food production due to the amount of its bioactive compounds. Main components (μg g^{-1} dried weight) are: kaempferol (34), myrcetin (65), isorhamnetin and derivatives (590), luteolin (8.4), ferulic acid and derivatives (1,050), and catechin (50). Obtaining these compounds could be a way of increasing cactus pear production profitability and creating jobs and value in rural areas. Cactus pear cultivation is a successful tool to mitigate climate change in arid and semiarid regions considering adequate farm and cultivation practices and systems. This crop is often located in high rurality areas, cultivated by small and micro-farmers. Cactus pear cultivation can be an effective tool for rural development in European arid and semiarid areas regarding production, job creation and environmental issues.

1. Introduction

Opuntia is a genus of plants of dicotyledonous angiosperm *Cactaceae* family (which includes ~1500 species) and part of natural environment and agricultural systems in arid areas. They are native to America, where they grow wild from the south part of the USA to the Patagonia. Cactus pear is cultivated worldwide (America, Asia, Europe, Africa and Oceania) as it grows in arid and semi-arid pedoclimatic zones and is the most important economic cactus species (Inglese et al., 2002).

Opuntia (*O. ficus-indica* or *O. amyclaea*) was one of the first species that came from the New World. It arrived into Europe through Spanish conquerors to make profit of unproductive soils in the south of the Iberian Peninsula (1548–1570). The idea was to cultivate it as food for carmine cochineal (*Dactylopius coccus* Costa) used to produce dyes. The plan failed but *Opuntia ficus-indica* soon found its place as a wild plant, natural fencing between land boundaries, cattle feed and human food.

Although *Opuntias* have been used as an important subsistence crop in many communities worldwide, fruit consumption remains limited to local ethnic markets with little export. Only Mexico, Italy, Chile, South Africa and Argentina produce it commercially (Reyes-Agüero et al., 2013) and cactus pear benefits from good marketing strategies in Italy, Mexico, the USA and South Africa (Inglese et al., 2002).

Mexico is the world largest producer (45% of world production), followed by Italy (12.2%) and South Africa (3.7%) (ISTAT Data Bank, 2013). In Mexico, the cactus pear sector creates employment and income in areas where few other crops can be produced (Timpanaro et al., 2015); ~20,000 families live from its cultivation (Gallegos-Vazquez et al., 2013). The planted area covers 50,000–70,000 ha, and the gross annual production ranges 300,000–500,000 t; it is the 5th fruit crop in the country.

* Corresponding author.
E-mail address: david.lopez@umh.es (D. López-Lluch).

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The 2nd world producer (and leading world exporter) is Italy, with 7000–8300 ha producing 78,000–87,000 t yearly (Timpanaro et al., 2015), while South Africa farms 1500 ha and produces 15,000 t. Chile (1100 ha and 8000 t), Argentina (800 ha and 7500 t), and USA (200 ha and 4000 t) also have significant figures, while countries such as Bolivia, Brazil, Jordan, Egypt, Pakistan, Israel, Tunisia, Algeria, Morocco and Spain also cultivate this plant (Inglese et al., 2017). However, limits of statistics collection hinder getting an accurate image of cactus pear production in these countries. Furthermore, fruit relatively low economic and social importance makes difficult that world organizations (EU, FAO, OECD, World Bank, etc.) supply consistent economic data about areas, production, employment, gross sales, export figures, etc.

There has been a general improvement in orchard techniques over the last years but there is also a lot of work to be done to change producers' perception and convince them that cactus pear can produce high yields and good quality if it receives right care and attention. It is critical to forget the wrong idea that cactus pear needs few inputs for good results; this wrong believe has led to bad management of cactus pear plantations and poor fruit quality. Thus, current knowledge remains scarce and limited scientific information arrives to producers (Inglese et al., 2002). However, the Italian experience proves that rational orchard management can give high returns and high quality fruit with relatively low management costs. To improve productivity and fruit quality, there must be greater awareness of environment and orchard management effects on fertility, fruit growth and ripening. It is also important to establish fruit quality standards and implement proper orchard design and management.

Consequently, providing the latest technical and scientific information about crop cultivation and post-harvest management, productivity levels and especially fruit quality standards to farmers should allow cactus pear competing on an equal basis with other agricultural products on international markets. Furthermore, attracting new consumers to cactus pears and creating higher demand requires consistent high-quality fruit availability (Inglese et al., 2017).

Increased fruit productivity is easier to achieve than improved fruit quality. Thus, special attention should be given to all horticultural practices potentially affecting fruit quality, at both pre- and post-harvest stages. In this sense, cactus pear fruit is usually consumed fresh, but increasing market demand for health-promoting food has prompted food technologists to develop techniques to increase its shelf life and to develop new and attractive products (Barba et al., 2017).

Regarding sales and profits, there is potential for development through a wide range of applications, including forage complement (Inácio et al., 2020; Monteiro et al., 2018), human consumption (including cladodes) both fresh and processed food, bio-functional, medicinal, nutraceutical and cosmetic uses, dyes production and bio-energy (Inglese et al., 2017). Fruits could be important commercially as they are well appreciated by consumers and have excellent nutritional properties (Cefola et al., 2014). Fruits are consumed fresh and used for food product manufacture such as juices (Ennouri et al., 2006), alcoholic beverages, jams and natural liquid sweeteners (Saenz, 2000). Regarding its polyphenols, vitamins and other specific compounds composition, cactus pear is an excellent candidate for nutritional diet and therapeutic recommendations (El-Mostafa et al., 2014). So, benefits from its cultivation are more than just fresh fruit production (Isaac, 2016).

First, there is a vast potential for non-food uses, exploiting its bio-functional, medicinal, nutraceutical and cosmetic properties. Prickly pears chemical and nutritional components have been recently studied (Antunes-Ricardo et al., 2015; Andreu et al., 2017; Melgar et al., 2017; Andreu-Coll et al., 2019; Mena et al., 2018) and their extracts hold antiulcerogenic, anti-inflammatory, antidiabetic, antioxidant, anti-cancer, neuroprotective, hepatoprotective and antiproliferative activities (Santos Diáz et al., 2017). Besides they are a good source for red and yellow food coloring agents (García-Cayuela et al., 2019). Another interesting possibility, it is production of bioethanol and biogas from cladodes. However, due to Spanish production structure, this potential has not been yet analyzed.

Table 1 shows quantities of compounds with bio-functional, medicinal, nutraceutical and cosmetic properties in several crops, with *Opuntia* playing a key role; however, no economic value analysis of cactus pear cultivation based on the production of these compounds has been done until now.

Second, environmental issues related to agriculture must be considered. Among agriculture environmental implications, climate change mitigation through soil carbon sequestration (SCS) is a key question. SCS is an affordable and cost-effective way to mitigate agriculture effect in climate change (Glenk and Colombo, 2011). Countries that signed the Kyoto Protocol of the United Nations Framework Convention on Climate Change agreed to lower CO_2 emissions to the atmosphere or increase removal and storage rates. The interest in C sequestration and trading as mechanisms for both environmental protection and poverty alleviation in developing countries has increased considerably in the last decades (Perez et al., 2007). Arid Mediterranean agriculture possesses a SCS potential. The case of olive tree cultivation is well documented; changing practices in favor of more sustainable agricultural procedures (Nieto et al., 2012) has been proved to be successful in increasing SCS (Rodríguez-Entrena & Arriaza, 2013). Furthermore, implementing these soil-management practices also improves soil structure (Castro et al., 2008), reduces water losses, prevents soil erosion (Nieto et al., 2012), and preserves biodiversity and landscape amenity aspects (Glenk & Colombo, 2011). Overall, they increase agricultural land adaptive capacity against adverse climate change impacts (Frelih-Larsen et al., 2008).

Cactus pear is one of the few agricultural options due to the edaphic and climatic conditions in many areas, presenting advantages over other agricultural activities because of practices that attenuate, avoid and even restore damage to the productive ecosystem (Nefzaoui et al., 2014).

Bautista-Cruz et al. (2018) compared C–CO_2 emission patterns and total organic carbon (TOC) in a central Mexico highland. They compared different management systems including cactus without and with composted manure mulching and soil in oak-pine forest. Their results showed that cactus crop is presently contributing effectively to soil TOC.

An important question is how to achieve that these agricultural sustainable practices, that mitigate climate change, become part of producers' way of cultivating. From a policy perspective, Agri-Environment Climate Scheme (AECS) have been regarded as the most suitable instrument to increase agriculture environmental performance and could represent an interesting tool for SCS strategy development in agriculture (Colombo & Rocamora-Montiel, 2018).

ROAECS (Results Orientated Agro-Environment Climate Scheme) is a type of agro-environmental scheme based on the idea of paying farmers, not for performing management actions, but for achieving specific environmental goals (Burton & Schwarz, 2013). ROAECS encourage farmers innovation, drawing on their experience and local knowledge to achieve improved and more cost-effective results (Colombo & Rocamora-Montiel, 2018). A key factor to ensure reliability in ROAECS development is the existence of measurable and objective indicators (Burton & Schwarz, 2013), which must be clearly measurable, attributable to specific management actions, not in conflict with agricultural goals and consistent with ecological purposes.

In this sense, sequestration of carbon (SOC) can be measured and monitored through various laboratory and field methods by using appropriate sampling procedures (Colombo & Rocamora-Montiel, 2018). In cactus pear orchards, SOC indicator totally fulfils the mentioned requirements opening opportunities to ensure sustained income and a moderate environment impact. Cactus pear plantations could be part of a strategy to lessen CO_2 atmosphere accumulation in arid and semi-arid areas implementing ROAECS. They can function as a water reserve and as a carbon reservoir offering a cost-effective contribution to climate change mitigation from the agricultural sector reducing soil erosion and water pollution.

Table 1
Quantities of compounds with bio-functional, medicinal, nutraceutical and cosmetic properties in several crop (μg g^{-1} dw).

Compound	*Opuntia ficus-indica*	*Opuntia joconostle* (1)	*Ziziphus jujube* (2)	*Stenocereus pruinosus* (3)	*Stenocereus stellatus* (3)	*Punica granatum* (4)
Kaempferol	34.1	139	39.17	nd	3.78	nd
Myrcetin	65	nd	nd	nd	nd	nd
Isorhamnetin and derivatives	590	nd	nd	2.53	nd	nd
Luteolin	8.40	nd	nd	nd	nd	nd
Ferulic acid and derivatives	1050	70	nd	8.8	36.8	nd
Catechin and derivatives	50.0	346	29.9	nd	nd	nd
Guaiacyl and derivatives	165	nd	nd	nd	nd	nd
Syringic acid and derivatives	165	33.9	nd	nd	nd	nd
Sinapic acid and derivatives	1140	nd	nd	nd	nd	nd
Quercetin and derivatives	91.1	225	148	3.53	7.14	nd
Narigin and derivatives	75.0	nd	nd	nd	22.5	nd
4-Hydroxy-benzoic acid	665	104	nd	nd	nd	nd
Eriodictyol derivative	nd	nd	2.67	nd	23.3	nd
Phloretin-3′,5′-di-glucoside	nd	nd	1.62	nd	nd	nd
Polymeric proanthocyanidins	nd	nd	1631	nd	nd	nd
Caffeic acid and derivatives	nd	nd	nd	34.3	29.4	135
p-coumaric acid and derivatives	nd	nd	nd	9.8	17.8	114
Gallic acid	nd	113	nd	nd	nd	175
Vanillic acid	nd	178	nd	nd	nd	nd
Elagic acid	nd	nd	nd	nd	nd	231
Rutin	nd	53.6	nd	nd	nd	nd
Taxifolin acetylhexoside	nd	nd	nd	5.25	14.6	nd
Total polyphenols	3426	1175	2254	64.7	131	655

(1) Cortez-García et al. (2015); (2) Wojdyło et al. (2016); (3) García-Cruz et al. (2017); (4) Elfalleh et al. (2011); nd = not detected.

Third, the crop is often located in high rurality areas, cultivated by small and micro-farmers. This makes it attractive from a strategic viewpoint and it should be seriously considered in public policy development actions, especially in arid and semi – arid areas.

Considering all previous considerations, this study had 3 aims: (i) economic evaluation of cactus pear production structure and costs in Mexico (main world producer), Italy (main world exporter) and Spain, special attention will be paid to establish the main economic and market features precluding *Opuntia* successful implementation in Spanish rural arid areas; (ii) economic analysis of cactus pear bio-functional, medicinal, nutraceutical and cosmetic properties; and (iii) economic estimation of carbon soil sequestration schemes possibilities in cactus pear production considering environmental issues.

2. Tools used for calculating the estimates

2.1. Economic evaluation of cactus pear production structure

First, production environment for Mexico, Italy and Spain was compared. Then, economic evaluation of cactus pear production structure was done through cost accounting (Romero et al., 2006). All operations are considered self-financing to avoid introducing financial variables. Economic assessment does not include fixed costs because these costs can introduce bias that do not affect the production process.

Data from other countries were obtained through published research (Basile et al., 2002; Losada et al., 2017). Average value of 1.0 € equal to 1.129 US$ is considered during 2017 (European Central Bank, 2018) for comparisons with Losada et al. (2017) and 1.259 for comparisons with Timpanaro & Foti (2014). Information was updated using inflation information from European Central Bank (2018).

Spanish production information was obtained through *in situ* interviews in three steps: (i) open interviews with farmers; (ii) questionnaires sent by post; and, (iii) audits and information validations with specific questions directed to interviewees. This data collection covered 3 full seasons in Spain.

The total variable production cost was established and was included in working assets costs. Opportunity costs were calculated as the next-best alternative use of working capital in risk-free financial assets; 2.0% interest rate was assumed, depending on money current cost and inflation adjustment.

Production variables obtained from secondary data and interviews (Table 2) were used to calculate costs and incomes. Differences in categories are due to the different processes undertaken for getting information and to country cultivation techniques differences. Gross income and total variable costs can be calculated by using contribution margin (CM), which is the margin used before considering depreciation and fixed costs. CM is calculated by taking the difference between gross incomes (GI) and incremental costs or variable costs (IC).

2.2. Economic analysis of cactus pears bio-functional, medicinal, nutraceutical and cosmetic properties

Data about the contents of components with bio-functional, medicinal, nutraceutical and cosmetic properties found in cactus pears has been reviewed and will be presented in tables together with economic data regarding their cost and estimated prices. Market prices of these compounds were obtained through a questionnaire among main

Table 2
Cactus pear production cost structure (€ ha^{-1}).

Item	Mexico (1) (€ ha^{-1})	Italy (2)	Spain
Tools	198.40		
Weeding	163.86		77.37
Pruning	54.91		55.26
Fertilization	55.80	383.4	
Fumigation (pests)	69.08	142.35	389.47
Others		25.8	
Pruning, *scozzolatura*, fruit thinning		1330.65	
Other cultivation operations		393	
Harvest	326.83		442.11
Transport	181.57		
Mechanized operations		394.5	
Brooms	4.42		
Straw	51.37		
Gloves	8.85		
Cost of crates	2.65		
Watering		309.45	344.24
Thinning			221.05
Insurances and taxes		383.25	260.52
Wages and salaries		326.7	7663,42
TOTAL	**939.77**	**4055.1**	**9453.77**

(1) Adapted from Losada et al. (2017); (2) adapted from Basile et al. (2002) and Timpanaro & Foti (2014).

producers. Then, an estimation of the quantities that could be obtained from 1 ha of cactus pear in Spain was calculated considering production data obtained in questionnaires carried out to producers.

2.3. Economic estimation of cactus pear production value considering environmental issues

An estimate of cactus plant CO_2 accumulation will be presented based on scientific literature together with the price to be paid for carbon sequestration, which was calculated considering not only carbon sequestration but also the benefits on the environment generated by its cultivation.

To estimate the exchange surface of each plant, 50 of them were measured in width, height and length. Then, number of cladodes *per* plant was counted and 20 of each were measured in height and length to estimate their surface area. Plant average area and average cladode surface were calculated to estimate exchange surface and CO_2 daily net intake *per* m^2 and day. Cactus plant weight was calculated counting cladodes per plant and weighting 25 of them; roots were not considered.

3. Discussion on economic estimates for the potential implementation of *Opuntia ficus-indica* in Spain

3.1. Characterization of fruit productive environment

3.1.1. Mexico

Mexico has introduced significant changes in cactus pear production recently, including drip irrigation in semi-arid areas, cultivation in less arid areas (central highlands and some subtropical regions in central south and western parts of the country), use of mechanical fruit-cleaning technologies, improved packing materials and modern commercial presentations. According to Losada et al. (2017), Mexican orchard size ranges 1–20 ha, with predominant size being 1–3 ha (64% of producers), 23% from 4 to 8 ha (23%), and 12–20 ha (9%). The main produced variety is pale green Alfayuca (*Opuntia amyclaea*). The distance between plants and rows goes from 4 to 6 m and orchard age from 20 to 70 years. They are pruned when they reach 1.5–2.0 m height (to facilitate fruit picking) (February–April). Fertilization is mainly done using triple 17 (17 N - 17 P_2O_5 - 17 K_2O) and urea (46 N), without a clear period for inorganic fertilizer use. Organic material is used, once or twice *per* year, mainly as manure because it is free and only transport cost applies, 15–60 kg of dry manure *per* plant (500 t ha^{-1}) depending on availability and orchard age. Prickly pear is very prone to pests and diseases. Producers constantly try to avoid them especially during post-harvest (Inglese et al., 2017). The production cycle, in a commercial orchard, starts in March (after frosts), increases in April, rises significantly during June and falls in September, October and November. The yield *per* ha is 10–15 t.

3.1.2. Italy

Italy represents an atypical example of *Opuntia ficus-indica* appreciation. Cactus pear has been exploited since the 18th century but with no commercial purposes, such as farm fencing and emergency fodder. Cactus pear is mainly cultivated in southern regions: Sicily, Sardinia, Calabria and Apulia. However, cultivation concentrates on Sicily (96%) with 4 important geographical areas: San Cono, Volcano Etna, Roccapalumba and Santa Margherita Belice. The most cultivated cultivars are "Gialla", "Rossa" and "Bianca", with "yellow" varieties predominating (~75%), followed by "red" and "white" ones. Sicilian orchard average size is less than 3 ha (Basile et al., 2002), with a plantation density from 300 to 900 plants *per* ha. Rainfall is 600 mm per year and under irrigation, the yield can reach 25 t *per* ha. Traditional use of simple and complex (binary and ternary) mineral fertilizers is common and countered by a generalized use of stable manure or other organic manures. Weeding with glyphosate for fighting the fruit fly and scabious rust with products based on dimethoate in conventional cultivation are also frequent. Mechanical weeding, use of traps (organic auxiliaries) and natural insecticides in organic cultivation are other techniques. Running a cactus pear plot requires a relatively high number of labor hours, although recent technical progress has made possible a partial reduction of tasks. However, due to their specific nature of some cultivation operations, such as pruning, *scozzolatura* and thinning, must be done manually. Apulia production is around 2650 t in 320 ha, mainly in Foggia province (North Apulia) with selected (spineless) cultivars. Initially, Sicilian cactus pear production was exported to the continent. This economic success was reinforced by *scozzolatura* technique. This ancient practice, developed by Italians at the beginning of the 18th century, consists of cutting off May first flowering production. The plant is forced into a second more abundant flowering during full summer period (July/August). It delays fructification, allowing autumn harvesting, producing better quality fruits than in the regular August season (Inglese et al., 2017). Autumn harvest (August–November) represents 90% of total production.

3.1.3. Spain

In Spain cactus pear is cultivated only in few family plantations in Andalusia, Murcia, Almeria and the Balearic Islands, with Lanzarote (Canary Islands) having a small production of red dye (Inglese et al., 2017). *O. ficus-indica* regular crops cover around 185 ha with an estimation of ~131,360 disseminated plants. Orchard average size is 15 ha, with a plantation framework of 2 m × 7 m (between plants and rows, respectively) and 714 plants *per* ha. As a cultivated plant, prickly pear life is approximately 20 years. Orchards are irrigated 4 times a week (2–3 h *per* ha) during May and June through drip irrigation in dry years, using municipal-treated wastewater. Pruning, weeding, thinning and harvesting are done manually. Pruning is only for renewal purpose (daily, for 15–30 min *per* ha) and weeding is only made in the streets (once a year); these labors do not require many working hours. But, thinning requires more work, being done during a full month for 5–6 h *per* ha daily. Harvesting requires more time, because it is a very delicate labor due to fruit spines or prickles. To facilitate this labor, long-arm tongs are used and it is usually done early in the morning, preventing prickles from getting rigid and inserting into the farmer body. Prickles removal and packaging (13–14 kg boxes) are also done manually; a person can pack 30–75 kg of fruit *per* h, considering removal, accommodation and fruit weighing. In general, no fertilizers nor organic matter are used. About phytosanitary products, main active substances are dimethoate (1.5%) and chlorpyrifos (2%) for preventing Mediterranean fruit fly (*Ceratitis capitata*) and cochineal (*Dactylopius coccus*), respectively. Chlorpyrifos treatment is done approximately once a month but not during the harvest period (August and September). In contrast, dimethoate treatment is carried out every two weeks from the second half of July to the end of September. Official Spanish production is around 720 t *per* year (MAPA, 2018), but real production is difficult to quantify.

3.2. Cost analysis

Table 2 shows cactus pear production cost analysis for Mexico, Italy and Spain, and shows clear differences among countries. With the main costs being harvest, pruning/*scozzolatura*/thinning and wages/salaries in Mexico, Italy and Spain, respectively.

3.3. Analysis of the gross economic profit margin

Mexican average production *per* ha is approximately 12.8 t ha^{-1} (400 crates), with a selling price of 3.2 € *per* crate (Losada et al., 2017); this gives a total of 1280 € *per* ha planted and a profit of ~340 € *per* ha.

Italian average production *per* ha is approximately 15.1 t ha^{-1} (Basile et al., 2002). Timpanaro & Foti (2014) calculate farm incomes considering fruit market value in 2013 at different producing areas. By combining average yields and prices, average farm incomes vary from

4756 € ha^{-1} for "*Belice Valley*" to 6672 € ha^{-1} for "*San Cono Hills*" (+40% of the minimum). Thus, the average income is 5714 € *per* ha, leading to an average profit of 1659 € *per* ha.

Spanish average production *per* ha is 234 t ha^{-1} (range 195–273). Prices ranges between 1.05 and 1.8 € *per* kg. Average income is 555,255 € *per* ha leading to an average profit of 545,801 € *per* ha.

3.4. Economic analysis of cactus pears production regarding bio-functional, medicinal, nutraceutical and cosmetic properties

Table 3 shows average content of bio-functional, medicinal, nutraceutical and cosmetic components in cactus pears according to published research. Table 4 summarizes average commercial quantities and prices, average quantity for the main bio-functional, medicinal, nutraceutical and cosmetic components and value (€) of 1 g of cactus (dry weight, dw) according to its composition.

The next step in the analysis is looking at the cost of obtaining these compounds in prickly pear. These processes and their costs depend on the type of plant material and compound to be extracted. There are no studies on these and in-depth cost analysis should be done considering the estimated value shown in Table 4. This will give an estimate of the viability of cultivating *Opuntia* for these purposes.

3.5. Economic estimation of cactus pear production value considering environmental issues

Most plants open stomata at dawn, taking CO_2 from the atmosphere, which is incorporated into various products of photosynthesis. Diurnal opening of stomata leads to an inevitable loss of water from leaves and meristematic stems. CO_2 intake and water loss occur mainly at night in *Opuntias*, when temperature is lower and humidity is higher, reducing water loss. CO_2 intake and *Opuntia* biomass accumulation depend on environmental conditions, mainly soil water content, air temperature, light and various soil elements. Allegra et al. (2015) and Pimienta-Barrios et al. (2005) quantified this CO_2 intake (Table 5); their data considered close-to-optimal temperatures, wet soil and indicated photosynthetic photon flow (PPF), and showed that *O. ficus-indica* takes 550 mol CO_2 m^2 daily.

Table 3
Average quantity of bio-functional, medicinal, nutraceutical and cosmetic components in cactus pears (μg g^{-1} dried weight, dw).

Compound	Average content (μg g^{-1} dw)	References
Kaempferol	34.04	El-Mostafa et al. (2014), García-Cayuela et al. (2019), Mena et al. (2018)
Myrcetin	65	Mena et al. (2018)
Isorhamnetin (and derivatives)	590	El-Mostafa et al. (2014), García-Cayuela et al. (2019), Mena et al. (2018), Yeddes et al. (2013)
Luteolin	8.4	El-Mostafa et al. (2014)
Ferulic acid (and derivatives)	1050	Mena et al. (2018)
Catechin	50	Mena et al. (2018)
Guaiacyl(t8-*O*-4) guaiacyl-hexoside	105	Mena et al. (2018)
Guaiacyl(8-*O*-4) syrinigyl(8–8) guaiacyl-hexoside	60	Mena et al. (2018)
Syrinigyl(t8-*O*-4) guaiacyl	60	Mena et al. (2018)
Sinapic acid (and derivatives)	1140	Mena et al. (2018)
Quercetin (and derivatives)	91.1	El-Mostafa et al. (2014), García-Cayuela et al. (2019), Mena et al. (2018), Yeddes et al. (2013)
Narigin (and derivatives)	75	Mena et al. (2018)
Syringaresinol	105	Mena et al. (2018)
4-Hydroxy-benzoic acid	665	García-Cayuela et al. (2019)
Piscidic acid	18865	García-Cayuela et al. (2019)
Betaxantins	196	Cano et al. (2017); García-Cayuela et al. (2019)
Betacyanins	328	Albano et al. (2015); Cano et al. (2017), García-Cayuela et al. (2019)

Table 4
Average commercial quantities and prices, average quantity (in micrograms in a gram of cactus pear dry weight) for the main bio-functional, medicinal, nutraceutical and cosmetic components and value of each g of cactus (dry weight) according to its composition.

Compound	Weight	Average price (€)	Average price (€ $μg^{-1}$)	Average content (μg) in 1 g dw of cactus pear	Value (€) of 1 g dw of cactus pear
Kaempferol (520-18-3)	20 mg	213.68	0.010684	34.04	0.36
Myricetin (529-44-2)	20 mg	238.11	0.011906	65	0.77
Rhamnetin (90-19-7)	10 mg	198.42	0.019842		
Fisetin (528-48-3)	10 mg	195.37	0.019537		
Isorhamnetin (480-19-3)	10 mg	204.53	0.020453	589.87	12.06
Myrcene (123-35-3)	100 mg	134.32	0.0013432		
Galangin (548-83-4)	20 mg	225.89	0.0112945		
Kaempferide (491-54-3)	10 mg	177.05	0.017705		
Luteolin (491-70-3)	10 mg	189.26	0.018926	8.4	0.16
Ferulic acid (537-98-4)	1 g	134.32	0.134320	1050	141.04
Gossypetin (489-35-0)	10 mg	265.58	0.026558		
4-Coumaric acid (501-98-4)	1 g	134.32	0.00013432		
3-Coumaric acid (14755-02-3)	1 g	134.32	0.00013432		
2-Coumaric acid (614-60-8)	1 g	134.32	0.00013432		
(+)- Catechin (154-23-4)	10 mg	186.21	0.018621	50	0.93
Morin (480-16-0)	20 mg	195.37	0.0097685		

Considering data from 3 Spanish orchards, as an average, a 5-years-old *O. ficus-indica* plant has 75 cladodes with an average cladode area of 0.09 m^2 (0.45 m × 0.21 m). This leads to a plant average area of 7.8 m^2. The average plant density is 714 plants *per* ha. Thus 1 ha will contain 5060.47 m^2 of cladodes, implying that 1 ha of *O. ficus-indica* can take 2,783,261 mol CO_2 *per* d (63.25 kg d^{-1}). An *O. ficus-indica* plant is fully productive when it is 5 years old and can reach 20 years of full production. Consequently, 1 ha of *O. ficus-indica* can take ~462 t of CO_2 during its complete productive life.

The number of cladodes were counted in 50 plants to estimate a cactus plant weight. Three cladodes *per* plant were weighted. A young plant (6–8 years old) presents 150 cladodes with an average weight of 2.5 kg each. An adult plant (20 years old) reaches, as average, 250 cladodes, leading to ~625 kg *per* adult plant. According to El-Mostafa et al. (2014), García-Cayuela et al. (2019), Mena et al. (2018) average water quantity of cactus pear is 80%. Thus, an adult cactus pear plant has 125 kg of dry mass.

Gomez-Casanovas et al. (2007) indicate that C content in a cladode is 36.2%. Thus, an adult plant has 45.25 kg of C (~166 kg of CO_2). As a result, an adult cactus pear plant fixes 8.29 kg of CO_2 *per* year through its

Table 5
Average temperature (T), daily total photosynthetic photon flow (PPF), soil water potential and CO_2 daily net intake for cultivated CAM plants in monitored laboratory conditions.

CAM plants	Day/night average air T (°C/°C)	PPF (mol m^2 d^{-1})	Soil water potential (MPa)	CO_2 daily net intake (mol m^{-2} d^{-1})	CO_2 net intake periods			CO_2 daily net intake contribution (%)	
					Day	Night	Total	Day	Night
Agave salmania	25/15	22	−0.2	481	5	12	17	3	97
Agave tequilina	15/10	22	−0.1	298	6	12	18	30	70
O. ficus-indica	25/10	20	−0.1	550	3	12	15	10	10
Sten. queretaroensis	28/15	19	−0.2	317	6	12	18	14	14

Source: Adapted from Allegra et al. (2015) and Pimienta-Barrios et al. (2005).

cladodes. This value should be revised and checked with in-depth studies, but it allows estimating the value of 1 ha considering environmental issues.

Bautista-Cruz et al. (2018) showed how cactus crop can contribute effectively to soil accumulation of organic carbon. Thus, cactus pear cultivation can be a successful way to mitigate climate change in arid and semiarid regions. Obviously, the amount of CO_2 remaining in the soil will depend on the agricultural practices applied by the farmers. A major concern is how to implement and achieve that sustainable practices helping to mitigate climate change become part of farmers' way of cultivating. As presented, ROAECS are agro-environmental schemes based on the idea of paying landowners for achieving specific environmental outcomes. ROAECS could be designed to adapt cactus pear production and management practices defining measurable and objective indicators consistent with ecological goals. SOC in cactus pear farms can be an effective indicator as it totally fulfils the stated requirements. Cactus pear plantations can function, not only as a water reserve, but as a carbon reservoir in arid and semi-arid regions offering a cost-effective agricultural contribution to climate change mitigation. Furthermore, it will reduce soil erosion and water pollution.

Carbon price is an issue to be analyzed. According to Point Carbon (Reuters, 2014), carbon price estimates would remain below 10 € during 2015 and 2016, dropping below 5 € in 2020, but rising steeply up to around 50 € by 2030. Carbon was marketed in recent years within the EU Carbon Trading Scheme, starting from a value close to 30 € *per* t of CO_2 in 2008 (Carbon Market Watch, 2014), since 2012 price has persistently been under 10 € t *per* t of CO_2 until March , 2018 and being over 20 € *per* t since December , 2018. Given carbon price ranges and the uncertainty over prices might apply, various scenarios should be considered. 2020 current average value, according to European bourse for Unit Allowances and Carbon Credits (SENDECO2, 2020), is around 25 € *per* t of CO_2. A 20 € value could, therefore, represent an average estimate during 2020–2030, but as previously stated, there can be no guarantee for future carbon prices (UK-Department of Energy and Climate Change, 2013).

4. Conclusions

This study had 3 aims and conclusions will be summarized for each one of them:

1 *Economic evaluation of cactus pear production structure and costs in Mexico, Italy and Spain*. Production structure is different in each producing country, with Spain not being a real productive sector but consisting of isolated farms. The high price that the product reaches (and the profitability) is because the demand is much higher than the production. On the other hand, Italy presents a developed cactus pear producing sector. Spanish producers should look at Italy before growing to avoid problems derived of increasing production without real and effective distribution channels and mature demand.

2 *Economic analysis of cactus pear bio-functional, medicinal, nutraceutical and cosmetic properties*. Quantities of compounds with bio-functional, medicinal, nutraceutical and cosmetic properties in several crops have been analyzed; *Opuntia* holds the highest contents of several of these compounds. Average quantities and average prices of these highly demanded components compared with average quantity (in μg) of these components in 1 g of dried cactus pear have been presented. Further research should look at the cost of obtaining these compounds. Obtaining these compounds could increase profitability of cactus pear production and, thus, promote a comprehensive development of the rural areas in which the production takes place.

3 *Economic estimation of applying carbon soil sequestration schemes in cactus pear production considering environmental issues*. Cactus pear cultivation is a successful tool to mitigate climate change in arid and semiarid regions. Farm and cultivation practices and systems are key aspects of how cactus crop can contribute effectively to improve soil carbon sequestration. To better develop this issue, measurable and objective indicators consistent with ecological goals are required. Such indicators should also be used to establish sustainable production and management practices. Under a policy perspective, these indicators should be embraced in a ROAECS to boost their adoption among farmers.

As a general conclusion, cactus pear cultivation can be an effective tool for rural development in European arid and semiarid areas regarding production, job creation and environmental issues.

References

Albano, C., Negro, C., Tommasi, N., Gerardi, C., Mita, G., Miceli, A., de Bellis, L., & Blando, F. (2015). Betalains, phenols and antioxidant capacity in cactus pear [*Opuntia ficus-indica* (L.) Mill.] fruits from Apulia (South Italy) genotypes. *Antioxidants, 4*(2), 269–280. https://doi.org/10.3390/antiox4020269.

Allegra, A., Sortino, G., Miciletta, G., Riotto, M., Fasciana, T., & Inglese, P. (2015). The influence of harvest period and fruit ripeness at harvest on minimally processed cactus pears (*Opuntia ficus-indica* (L.) Mill.) stored under passive atmosphere. *Postharvest Biology and Technology, 104*, 57–62. https://doi.org/10.1016/j.postharvbio.2015.03.001.

Andreu-Coll, L., Cano-Lamadrid, M., Sendra, E., Carbonell-Barrachina, Á., Legua, P., & Hernández, F. (2019). Fatty acid profile of fruits (pulp and peel) and cladodes (young and old) of prickly pear [*Opuntia ficus-indica* (L.) Mill.] from six Spanish cultivars. *Journal of Food Composition and Analysis, 84*, Article 103294. https://doi.org/10.1016/j.jfca.2019.103294.

Andreu, L., Nuncio-Jáuregui, N., Carbonell-Barrachina, Á. A., Legua, P., & Hernández, F. (2017). Antioxidant properties and chemical characterization of Spanish *Opuntia ficus-indica* (L.) Mill . cladodes and fruits. *Journal of the Science of Food and Agriculture, 98*, 1566–1573. https://doi.org/10.1002/jsfa.8628.

Antunes-Ricardo, M., Gutiérrez-Uribe, J. A., López-Pacheco, F., Alvarez, M. M., & Serna-Saldívar, S. O. (2015). In vivo anti-inflammatory effects of isorhamnetin glycosides isolated from *Opuntia ficus-indica* (L.) Mill. cladodes. *Industrial Crops and Products, 76*, 803–808. https://doi.org/10.1016/j.indcrop.2015.05.089.

Barba, F. J., Putnik, P., Bursać Kovačević, D., Poojary, M. M., Roohinejad, S., Lorenzo, J. M., & Koubaa, M. (2017). Impact of conventional and non-conventional processing on prickly pear (*Opuntia* spp.) and their derived products: From preservation of beverages to valorization of by-products. *Trends in Food Science & Technology, 67*, 260–270. https://doi.org/10.1016/j.tifs.2017.07.012.

Basile, F., Foti, V. T., & Timpanaro, G. (2002). Comparative economic analyses between conventional and eco-compatible cactus pear cultivation in Italy. *Acta Horticulturae, 581*, 47–61. https://doi.org/10.17660/ActaHortic.2002.581.2.

Bautista Cruz, A., Leyva-Pablo, T., de León-González, F., Zornoza, R., Martínez-Gallegos, V., Fuentes-Ponce, M., & Rodríguez-Sánchez, L. (2018). Cultivation of *Opuntia ficus-indica* (L.) mill. Under different soil management practices: A possible sustainable agricultural system to promote soil carbon sequestration and increase soil microbial biomass and activity. *Land Degradation & Development, 29*(1), 38–46. https://doi.org/10.1002/ldr.2834.

Burton, R. J. F., & Schwarz, G. (2013). Result-oriented agri-environmental schemes in Europe and their potential for promoting behavioural change. *Land Use Policy, 30*(1), 628–641. https://doi.org/10.1016/j.landusepol.2012.05.002.

Cano, M. P., Gómez-Maqueo, A., García-Cayuela, T., & Welti-Chanes, J. (2017). Characterization of carotenoid profile of Spanish Sanguinos and Verdal prickly pear (*Opuntia ficus-indica*, spp.) tissues. *Food Chemistry, 237*, 612–622. https://doi.org/10.1016/j.foodchem.2017.05.135.

Carbon Market Watch. (2014). What 's needed to fix the EU 's carbon market Recommendations for the Market Stability Reserve and future ETS reform proposals. Book 8. Available online: https://carbonmarketwatch.org/publications/whats-needed-to-fix-the-eus-carbon-market-recommendations-for-the-market-stability-reserve-and-future-ets-reform-proposals/ (accessed on18 March 2020).

Castro, J., Fernández-Ondoño, E., Rodríguez, C., Lallena, A. M., Sierra, M., & Aguilar, J. (2008). Effects of different olive-grove management systems on the organic carbon and nitrogen content of the soil in Jaén (Spain). *Soil and Tillage Research, 98*(1), 56–67. https://doi.org/10.1016/j.still.2007.10.002.

Cefola, M., Renna, M., & Pace, B. (2014). Marketability of ready-to-eat cactus pear as affected by temperature and modified atmosphere. *Journal of Food Science & Technology, 51*(1), 25–33. https://doi.org/10.1007/s13197-011-0470-5.

Colombo, S., & Rocamora-Montiel, B. (2018). Result-oriented agri-environmental climate schemes as a means of promoting climate change mitigation in olive growing. *Outlook on Agriculture, 47*(2), 141–149. https://doi.org/10.1177/0030727018770931.

Cortez-García, R. M., Ortiz-Moreno, A., Zepeda-Vallejo, L. G., & Necoechea-Mondragón, H. (2015). Effects of cooking methods on phenolic compounds in Xoconostle (*Opuntia joconostle*). *Plant Foods for Human Nutrition, 70*(1), 85–90. https://doi.org/10.1007/s11130-014-0465-2.

El-Mostafa, K., El Kharrassi, Y., Badreddine, A., Andreoletti, P., Vamecq, J., El Kebbaj, M. S., Latruffe, N., Lizard, G., Nasser, B., & Cherkaoui-Malki, M. (2014). Nopal cactus (*Opuntia ficus-indica* (L.) Mill.) as a source of bioactive compounds for nutrition, health and disease. *Molecules, 19*(9), 14879–14901. https://doi.org/10.3390/molecules190914879.

Elfalleh, W., Tlili, N., Nasri, N., Yahia, Y., Hannachi, H., Chaira, N., Ying, M., & Ferchichi, A. (2011). Antioxidant capacities of phenolic compounds and tocopherols from Tunisian pomegranate (*Punica granatum*) fruits. *Journal of Food Science, 76*(5). https://doi.org/10.1111/j.1750-3841.2011.02179.x.

Ennouri, M., Bourret, E., Baklouti, S., Damak, K., Rebaï, A., & Attia, H. (2006). Rheology of microfiltrated prickly pear (*Opuntia* spp.) juices. *Sciences des Aliments, 26*(4), 337–348. https://doi.org/10.3166/sda.26.337-348.

European Central Bank. (2018). *ECB euro reference exchange rate: US dollar (USD)*. Available at: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html . (Accessed 30 March 2018) accessed on.

Frelih-Larsen, A., Leipprand, A., Naumann, S., & Beucher, O. (2008). *Policy incentives for climate change mitigation agricultural techniques "PICCMAT": Climate change mitigation through agricultural techniques - policy recommendations (deliverable D11)*. Berlin: Ecologic Institute. https://www.ecologic.eu/2087.

Gallegos Vázquez, C., Méndez Gallegos, S. J., & Mondragón Jacobo, C. (2013). Producción Sustentable de la Tuna en San Luis Potosí. In *Colegio de Postgraduados - fundación produce san luis potosí. San luis potosí*. A.C.

García-Cayuela, T., Gómez-Maqueo, A., Guajardo-Flores, D., Welti-Chanes, J., & Cano, M. P. (2019). Characterization and quantification of individual betalain and phenolic compounds in Mexican and Spanish prickly pear (*Opuntia ficus-indica* (L.) mill) tissues: A comparative study. *Journal of Food Composition and Analysis, 76*, 1–13. https://doi.org/10.1016/j.jfca.2018.11.002.

García-Cruz, L., Dueñas, M., Santos-Buelgas, C., Valle-Guadarrama, S., & Salinas-Moreno, Y. (2017). Betalains and phenolic compounds profiling and antioxidant capacity of pitaya (*Stenocereus* spp.) fruit from two species (*S. Pruinosus* and *S. stellatus*). *Food Chemistry, 234*, 111–118. https://doi.org/10.1016/j.foodchem.2017.04.174.

Glenk, K., & Colombo, S. (2011). Designing policies to mitigate the agricultural contribution to climate change: An assessment of soil based carbon sequestration and its ancillary effects. *Climatic Change, 105*(1), 43–66. https://doi.org/10.1007/s10584-010-9885-7.

Gomez-Casanovas, N., Blanc-Betes, E., Gonzalez-Meler, M. A., & Azcon-Bieto, J. (2007). Changes in respiratory mitochondrial machinery and cytochrome and alternative pathway activities in response to energy demand underlie the acclimation of respiration to elevated CO2 in the invasive *Opuntia ficus-indica* (L.) Mill. *Plant physiology, 145*(1), 49–61. https://doi.org/10.1104/pp.107.103911.

Inácio, J. G., Da Conceicąõ, M. G., Dos Santos, D. C., De Oliveira, J. C. V., Chagas, J. C. C., De Oliveira Moraes, G. S., Dos Santos Silva, E. T., & De Andrade Ferreira, M. (2020). Nutritional and performance viability of cactus *Opuntia*-based diets with different concentrate levels for Girolando lactating dairy cows. *Asian-Australasian Journal of Animal Sciences, 33*(1), 35–43. https://doi.org/10.5713/ajas.18.0916.

Inglese, P., Basile, F., & Schirra, M. (2002). *Cactus pear fruit production*.

Inglese, P., Mondragon, C., Nefzaoui, A., & Saenz, C. (2017). *Crop ecology, cultivation and uses of cactus pear*. Food and Agriculture Organization of the United Nations (FAO).

Isaac, A. A. (2016). Overview of cactus (*Opuntia ficus-indica* (L.) mill.: A myriad of alternatives. *Studies on Ethno-Medicine, 10*(2), 195–205. https://doi.org/10.1080/09735070.2016.11905488.

Istat Data Bank. (2013). Available online: http://agri.istat.it/sag_is_pdwout/excel/Dw302013.xls . (Accessed 26 July 2019) accessed on.

Losada, H. R., Vieyra, J. E., Luna, L., Cortés, J., & Vargas, J. M. (2017). Economic indicators, capacity of the ecosystem of prickly pear cactus (*Opuntia megacantha*) and environmental services in Teotihuacan, México to supply urban consumption. *Journal of Agriculture and Environmental Sciences, 6*(1), 85–91. https://doi.org/10.15640/jaes.v6n1a9.

Mapa. (2018). Anuario de Estadística agraria. *Ministerio de Agricultura, Pesca y Alimentación*. Available online https://www.mapa.gob.es/estadistica/pags/anuario/2018/CAPITULOSPDF/CAPITULO07/pdfc07_9.19.1.pdf. (Accessed 17 March 2020) accessed on.

Melgar, B., Dias, M. I., Ciric, A., Sokovic, M., Garcia-Castello, E. M., Rodriguez-Lopez, A. D., Barros, L., & Ferreira, I. (2017). By-product recovery of *Opuntia* spp. peels: Betalainic and phenolic profiles and bioactive properties. *Industrial Crops and Products, 107*, 353–359. https://doi.org/10.1016/j.indcrop.2017.06.011.

Mena, P., Tassotti, M., Andreu, L., Nuncio-Jáuregui, N., Legua, P., Del Rio, D., & Hernández, F. (2018). Phytochemical characterization of different prickly pear (*Opuntia ficus-indica* (L.) mill.) cultivars and botanical parts: UHPLC-ESI-MSn metabolomics profiles and their chemometric analysis. *Food Research International, 108*, 301–308. https://doi.org/10.1016/j.foodres.2018.03.062.

Monteiro, C. C. F., Ferreira, M. A., Veras, A. S. C., Guido, S. I., Almeida, M. P., Silva, R. C., & Inacio, J. G. (2018). A new cactus variety for dairy cows in areas infested with *Dactylopius opuntiae*. *Animal Production Science, 59*(3), 479–485. https://doi.org/10.1071/AN17256.

Nefzaoui, A., Louhaichi, M., & Ben Salem, H. (2014). Cactus as a tool to mitigate drought and to combat desertification. *Journal of Arid Land Studies, 24*(1), 121–124.

Nieto, O. M., Castro, J., & Fernández-Ondoño, E. (2012). Uso sustentável de solos de olival. Influência das técnicas de maneio nas suas propriedades. *Spanish Journal of Soil Science, 2*(1), 70–77. https://doi.org/10.3232/SJSS.2012.V2.N1.05.

Perez, C., Roncoli, C., Neely, C., & Steiner, J. L. (2007). Can carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges. *Agricultural Systems, 94*(1), 2–12. https://doi.org/10.1016/j.agsy.2005.09.009.

Pimienta-Barrios, E., Zañudo-Hernandez, J., Rosas-Espinoza, V. C., Valenzuela-Tapia, A., & Nobel, P. S. (2005). Young daughter cladodes affect CO2 uptake by mother cladodes of *Opuntia ficus-indica* (L.) Mill. *Annals Of Botany, 95*(2), 363–369. https://doi.org/10.1093/aob/mci034.

Reuters, T. (2014). EU carbon price to average €23/t between 2021 and 2030: Thomson Reuters assess the future. Available at: https://www.refinitiv.com/perspectives/market-insights/eu-carbon-price-average-e23t-2021-2030-thomson-reuters-assess-future. (Accessed 18 March 2020) (accessed on.

Reyes-Agüero, J. A., Aguirre, J. R., Carlín-Castelán, F., & González-Durán, A. (2013). Diversity of wild and cultivated opuntia variants in the meridional highlands plateau of Mexico. *Acta Horticulturae, 995*, 69–74. https://doi.org/10.17660/ActaHortic.2013.995.8.

Rodríguez-Entrena, M., & Arriaza, M. (2013). Adoption of conservation agriculture in olive groves: Evidences from southern Spain. *Land Use Policy, 34*, 294–300. https://doi.org/10.1016/j.landusepol.2013.04.002.

Romero, P., García, J., & Botía, P. (2006). Cost-benefit analysis of a regulated deficit-irrigated almond orchard under subsurface drip irrigation conditions in Southeastern Spain. *Irrigation Science, 24*(3), 175–184. https://doi.org/10.1007/s00271-005-0008-6.

Saenz, C. (2000). Processing technologies: An alternative for cactus pear (*Opuntia* spp.) fruits and cladodes. *Journal of Arid Environments, 46*(3), 209–225. https://doi.org/10.1006/jare.2000.0676.

Santos Díaz, M. del S., Barba De La Rosa, A. P., Héliès-Toussaint, C., Guéraud, F., & Nègre-Salvayre, A. (2017). *Opuntia* spp.: Characterization and benefits in chronic diseases. *Oxidative Medicine and Cellular Longevity*. https://doi.org/10.1155/2017/8634249. *2017*.

Sendeco2. (2020). Sistema electrónico de Negociación de Derechos de Emisión de Dióxido de Carbono. Available at: http://www.sendeco2.com/es/conocenos.asp. (Accessed 30 January 2020) accessed on.

Timpanaro, G., & Foti, V. T. (2014). The structural characteristics, Economic performance and prospects for the Italian cactus pear industry. *Journal of the Professional Association for Cactus Development, 16*, 32–50.

Timpanaro, G., Urso, A., Spampinato, D., & Foti, V. T. (2015). Cactus pear market in Italy: Competitiveness and perspectives. *Acta Horticulturae, 1067*, 407–415. https://doi.org/10.17660/ActaHortic.2015.1067.56.

Uk-Department of Energy and Climate Change. (2013). Updated short-term traded carbon values for policy appraisal. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/240095/shortterm_traded_carbon_values_used_for_UK_policy_appraisal_2013_FINAL_URN.pdf. (Accessed 18 March 2020) accessed on.

Wojdyło, A., Carbonell-Barrachina, Á. A., Legua, P., & Hernández, F. (2016). Phenolic composition, ascorbic acid content, and antioxidant capacity of Spanish jujube (*Ziziphus jujube* Mill.) fruits. *Food Chemistry, 201*, 307–314. https://doi.org/10.1016/j.foodchem.2016.01.090.

Yeddes, N., Chérif, J. K., Guyot, S., Sotin, H., & Ayadi, M. T. (2013). Comparative study of antioxidant power, polyphenols, flavonoids and betacyanins of the peel and pulp of three Tunisian *Opuntia* forms. *Antioxidants, 2*(2), 37–51. https://doi.org/10.3390/antiox2020037.