ELSEVIER

Journal of Arid Environments 68 (2007) 315–321

Journal of Arid Environments

www.elsevier.com/locate/jnlabr/yjare

Short communication

Potential of halophytes as source of edible oil

D.J. Weber[a,*], R. Ansari[b], B. Gul[b], M. Ajmal Khan[b]

[a]*Department of Integrated Biology, Brigham Young University, Provo, UT 84602, USA*
[b]*Department of Botany, University of Karachi, Karachi 75270, Pakistan*

Received 15 December 2005; received in revised form 22 May 2006; accepted 23 May 2006
Available online 20 July 2006

Abstract

Seeds of *Arthrocnemum indicum*, *Alhaji maurorum*, *Cressa cretica*, *Halopyrum mucronatum*, *Haloxylon stocksii* and *Suaeda fruticosa* were analyzed to determine their potential to be used as source of edible oil. The quantity of oil present varied from 22% to 25%. The amounts of unsaturated fatty acids were high (65–74%) except in *A. maurorum*. The lipids in the seeds were found to contain 12 unsaturated fatty acids and four saturated fatty acids. The ash content also ranged from 2%–39%. Our data clearly indicate that the seeds of halophytes particularly *S. fruticosa* could be used as a source of oil for human consumption.

Keywords: Fatty acids; Salinity; Suaeda fruticosa; Seed oil; Saline soils; Ions

The demand for vegetable oil in Pakistan has been increasing progressively and has seen rapid growth in this industry from two factory production units in 1947 to more than 40 factory production units in 1998 (Anonymous, 2005). Cottonseed is the major domestic source of edible oil followed by rape, mustard, and canola (Anonymous, 2005).

Despite of having a predominantly agrarian economy, Pakistan agriculture is unable to meet the national requirement of vegetable oil. The 70% short fall of edible oil requirement is currently met through import to the tune of Rs. 38 billion annually (Anonymous, 2005). Palm oil, which is injurious to health, constitutes the bulk of this import. Dietary studies support the concept that saturated fats are a greater risk for heart diseases than polyunsaturated fatty acids (Hu, 1997). Palm oil has 52% saturation whereas animal fats (lard) are 40%, and canola oil is 8% saturated (Declercq and Daun, 1998; Weber et al., 2001).

*Corresponding author. Tel.: +1 801 830 6091; fax: +1 801 422 0090.
E-mail address: Darrell_Weber@yahoo.com (D.J. Weber).

0140-1963/$ - see front matter
doi:10.1016/j.jaridenv.2006.05.010

Halophytes thrive under varying soil salinity conditions and may be irrigated with brackish water or with a certain percent of seawater without any major ill effects on growth and reproduction (Parida and Das, 2005). Seeds of many of these halophytes may contain appreciable quantities of edible oil (Glenn et al., 1991; Weber et al., 2001), however, research on halophyte oilseeds appears scanty. Oil extracted from the seeds of *Salicornia bigelovii*, a highly salt tolerant stem succulent annual halophyte, was reported to be of good quality, whose level of unsaturation was comparable to oils extracted from conventional oil seeds (Glenn et al., 1991). This was followed by a report of oils extracted from perennial halophytes distributed in the Great Basin desert of North America on total lipids and individual fatty acid fractions in five halophytic species indicating that the level of unsaturation ranged from 85% to 90%. The best quality oil was extracted from a highly salt tolerant perennial species *Suaeda moquinii* (Weber et al., 2001). This report clearly suggests that the quality of extracted oil is approaching the quality of the best edible oils (Olive and Canola) reported (Declercq and Daun, 1998). This observation is further supported by reports on other halophytes such as *Crithmum maritimum*, *Zygophyllum album* (Zarrouk et al., 2003), *Kosteletzkya virginica*, (He et al., 2003), *Nitraria sibiria*, *Suaeda salsa*, *Chenopodium glaucum* and *Descurainaia sophia* from China (Yajun et al., 2003), which indicate the presence of good quality oil. Yajun et al. (2003) also reported that *D. sophia* collected from saline soil (0.4% NaCl) contained higher amounts (53.7%) of linolenic acid in their seeds in comparison to those plants growing in non-saline soil (<0.1% salt), where about 36% linolenic acid was present. Linolenic acid is a precursor for producing prostaglandin in human body, which is helpful in dilating blood vessels, alleviating asthma, and in curing gastric ulcer (Anonymous, 1995).

Soil salinity in Pakistan, like any other country of arid and semi-arid regions, is on the increase, supplies of good quality irrigation water are limited and underground water is largely brackish (FAO, 2005). Most of the conventional crops do not survive moderate salinity stress. Alternate approaches to growing crops have to be found to meet the other requirements (edible oil being an important one) of the human population. This paper tests the hypothesis that seeds of some perennial halophytes distributed around Karachi and on adjoining coastal belt produce seeds containing oil acceptable for human consumption.

Halophytic species, which are found in abundance in Karachi and vicinity, were selected for the seed oil analysis. *Arthrocnemum macrostachyum* (Moric.) C. Koch (Chenopodiaceae) is a stem succulent perennial halophytic shrub, commonly found in tropical salt marshes which are frequently inundated with seawater (Karim and Qadir, 1979). *Haloxylon stocksii* (Boiss.) Benth. and Hook. (Chenopodiaceae) is a stem succulent perennial shrub which is found in highly saline soils, distributed from southern Pakistan to northern Himalayan valley of Chitral, Pakistan (Khan and Ungar, 1996a). *Suaeda fruticosa* (L.) Forssk. (Chenopodiaceae) is a leaf succulent perennial halophytic shrub which is highly salt tolerant and is widely distributed in inland and coastal salt marshes as well as in deserts of Pakistan. (Gulzar and Khan, 1998). *Alhagi maurorum* Medic. (Papilionaceae) is a spiny deciduous, perennial, salt marsh undershrub, native from Eurasia, commonly found in both inland and coastal areas of Karachi (Stewart, 1972). *Cressa cretica* Linn. (Convolvulaceae) is a dominant species of coastal salt marsh communities of Pakistan, usually occurring in mono specific stands along the landward edge of marshes. It regenerates vegetatively, but also produces a large number of seeds (Khan and Aziz, 1998). *Halopyrum mucronatum* (L.) Stapf. (Poaceae) is a perennial grass distributed along the coast from Egypt to Mozambique and Madagascar, through Arabia to Pakistan, India, and Sri Lanka, a major component of dune vegetation, it reproduces by underground stolons and sexually by caryopses (Jafri, 1966).

Seeds of *H. stocksii*, *S. fruticosa*, *A. maurorum*, *C. cretica*, and *H. mucronatum* were collected from salt flats situated on Karachi University campus, Pakistan, while seeds from *A. macrostachyum* came from a salt marsh located at Manora creek near Sandspit at Karachi, Pakistan.

The seeds were separated from the vegetative plant parts, cleaned, ground with a Wiley Mill and extracted three times with methanol and chloroform (1:2 v/v). The percent oil in seeds was determined by weight. Fatty acids in oil extracts were methylated with Altech. methyl prep. [(trifluromethyl phenyl) trimethylammonium hydroxide]. The methylated fatty acids were separated by capillary gas chromatography (Hp GC 6890) and identified by GC mass spectrometry (Hp MS 5973). The fatty acids were identified by matching the major fragments pattern with reference mass spectra of methyl ester fatty acids in the database.

The seeds were ground in a Wiley Mill and 0.5 g of the seed material was boiled for two hours at 100 °C using a dry heat bath. The hot water extract was cooled and filtered using Whatman no. 2 filter paper. One milliliter of hot water extract was diluted with distilled water for ion analysis. Nitrate and sulfate ion contents were measured with a DX 100 ion chromatograph. Cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) were analyzed using a Perkin-Elmer model 360 atomic absorption spectrophotometer. The ions (P, Fe, Mn, Zn, Cu) in the hot water extract were determined using an IRIS inductively coupled plasma (ICP) analyzer.

The seed oil content in the halophytes under study ranged between 22% and 25%. Seeds of *S. fruticosa* and *A. macrostachyum* both contained about 25% oil followed by *H. mucronatum* (22.7%), *C. cretica* (23.3%), *H. stocksii* (23.2%), and *A. maurorum* (21.9%). These differences were however, non-significant. The amount of unsaturated fatty acids (USFA) was between 65% and 74% of the total fatty acids. Seed oil from *S. fruticosa* (74% USFA) appeared to be the best from a health point of view and was followed by *H. stocksii* (69% USFA), *H. mucronatum* (70% USFA), *C. cretica* (64% USFA), *A. macrostachyum* (65% USFA), and *A. maurorum* (54% USFA).

Analysis of seed oil showed the presence of sixteen fatty acids of which twelve were saturated and four were unsaturated fatty acids (Table 1). The largest number of fatty acids was detected in *A. macrostachyum* (all sixteen) whereas *C. cretica* contained only eight (five saturated and three unsaturated). *A. macrostachyum* was also unique in being the only halophyte under study which had a low molecular weight ($C_{14:0}$) saturated fatty acid (myristic) in its oil. Palmitic ($C_{16:0}$) was the dominant saturated fatty acid in the seed oil whose quantity varied between 17% (in *S. fruticosa)* and 29% (in *A. maurorum*). The unsaturated fraction composition of oil from halophyte seeds showed that oleic and linolenic acids were absent whereas linoleic acid was the major fatty acid component (Table 1).

Ash content of halophyte seeds showed a great deal of variation ranging from 2% (*A. maurorum* and *H. mucronatum*) to 39% in *A. macrostachyum* (Table 2). Ion analysis of the seeds of halophytes showed presence of a number of important macro and micro mineral nutrients (N, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu) in variable quantities (Table 2). Total ion contents were the lowest in *H. mucronatum* and highest in *H. stocksii*, between these two extremes were *S. fruticosa*, *A. maurorum*, *A. macrostachyum*, and *C. cretica*.

The data presented here clearly indicate the potential to extract high-quality edible oil from seed bearing halophytes. The halophytes used in the present study contained 22–25%

Table 1
Saturated /un-saturated fatty acid fractions (%) in the oil of halophytes

Fatty acids	*Arthrocnemum macrostachyum*	*Haloxylon stocksii*	*Suaeda fruticosa*	*Alhagi maurorum*	*Cressa cretica*	*Halopyrum mucronatum*
Saturated						
Dodecanoic acid methyl ester (lauric) $C_{12:0}$	0.23 ± .01	0.38 ± .06	0.15 ± .03	0.11 ± .03	0.00 ± .00	0.00 ± .00
Tetradecanoic acid methyl ester (myristic) $C_{14:0}$	0.71 ± .01	0.00 ± .00	0.00 ± .00	0.00 ± .01	0.00 ± .00	0.00 ± .00
Pentadecanoic acid methyl ester $C_{15:0}$	0.52 ± .12	0.21 ± .01	0.16 ± .01	0.23 ± .01	0.00 ± .00	0.22 ± .09
Hexadecanoic acid methyl ester (palmitic) $C_{16:0}$	26.93 ± .01	21.79 ± .58	17.04 ± .69	29.38 ± .1	25.75 ± .82	24.20 ± 1.0
Octadecanoic acid methyl ester (stearic) $C_{18:0}$	3.17 ± .09	3.94 ± .26	4.61 ± .01	11.01 ± .08	8.26 ± .16	3.27 ± .18
Non-adecanoic acid methyl ester $C_{19:0}$	0.62 ± .08	0.93 ± .10	1.08 ± .13	0.16 ± .01	0.00 ± .00	0.00 ± .00
Eicosanoic acid methyl ester (arachdic) $C_{20:0}$	0.93 ± .02	1.56 ± .08	1.09 ± .07	1.57 ± .06	1.19 ± .03	0.93 ± .15
Heneicosanoic acid methyl ester $C_{21:0}$	0.15 ± .00	0.17 ± .01	0.00 ± .00	0.21 ± .01	0.00 ± .00	0.00 ± .00
Docosanoic acid methyl ester (behenic) $C_{22:0}$	1.00 ± .01	0.87 ± .06	0.83 ± .03	1.24 ± .03	0.28 ± .01	1.11 ± .14
Tricosanoic acid methyl ester $C_{23:0}$	0.22 ± .03	0.16 ± .01	0.24 ± .00	0.25 ± .01	0.00 ± .00	0.00 ± .00
Tetracosanoic acid methyl ester (lignoceric) $C_{24:0}$	0.63 ± .01	0.77 ± .10	0.85 ± .23	0.64 ± .01	0.28 ± .05	0.43 ± .09
Hexacosanoic acid methyl ester (cerotic) $C_{26:0}$	0.42 ± .03	0.11 ± .02	0.25 ± .01	0.00 ± .00	0.00 ± .00	0.00 ± .00
Total	35.53	30.89	25.75	44.69	35.76	30.16
Unsaturated						
9-Hexadecenoic acid methyl ester (palmitoleic) $C_{16:1}$	0.59 ± 0.01	0.46 ± 0.02	0.56 ± 0.05	0.23 ± 0.01	0.12 ± 0.01	0.35 ± .04
7-Hexadecenoic acid methyl ester (palmitoleic) $C_{16:1}$	0.28 ± 0.10	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	0.00 ± 0.00	0.00 ± .01
8, 11-Octadecadienoic acid methyl ester (linoleic) $C_{18:2}$	63.02 ± 0.26	66.24 ± 1.54	72.08 ± 1.08	53.28 ± 1.75	62.70 ± 0.87	68.43 ± 2.0
11-Eicosanoic acid methyl ester (gadoleic) $C_{20:1}$	0.56 ± 0.00	1.53 ± 0.12	0.65 ± 0.05	0.68 ± 0.07	0.63 ± 0.01	0.37 ± .07
Total	64.76	68.23	73.61	54.19	63.45	69.15

Table 2
Ion content of halophyte seeds

Plant species	Ions (%)					
	N	P	K	Ca	Mg	S
(A) Found in major (%) quantities						
Cressa cretica	2.48	0.38	0.71	3.19	0.21	0.18
Suaeda fruticosa	3.50	0.48	0.70	0.42	0.35	0.35
Halopyrum mucronatum	2.47	0.43	0.44	0.16	0.23	0.14
Alhagi maurorum	3.21	0.40	1.38	0.37	0.37	0.31
Arthrocnemum macrostachyum	1.86	0.25	0.35	2.61	0.61	0.49
Haloxylon stocksii	4.84	0.35	2.10	0.78	0.39	0.38

Plant species	Ions (ppm)					Ash (%)
	Na	Fe	Mn	Zn	Cu	
(B) Found in Minor (ppm) quantities						
Suaeda fruticosa	1623	762	60	62	20	7
Alhagi maurorum	607	144	29	48	15	2
Cressa cretica	310	1526	80	46	15	7
Halopyrum mucronatum	53	115	14	52	13	2
Arthrocnemum macrostachyum	3573	2398	119	67	22	39
Haloxylon stocksii	3550	132	52	43	19	20

oil which compares well with ca. 30% oil reported in *S. bigelovii* (Glenn et al., 1991; Bashan et al., 2000). Weber et al. (2001) reported oil recovery from a low of 10% in *Kochia scoparia* to 26% in *Suaeda torreyana* and He et al. (2003) reported 11% oil recovery from seed of *K. virginica*. Yajun et al. (2003) found oil recovery ranging from 9% to 35% in four halophytes of their study.

Data for the best conventional oil seeds crop indicate that canola produces the best oil for human consumption. The oil recovery from canola seed is 40% with over 90% unsaturated fatty acid contents (Declercq and Daun, 1998). Halophytes such as *Cakile edentula* (O'Leary et al., 1985) and *Crambe abysinnica* (Mandal et al., 2002) have been reported to contain 50% and 60% oil, respectively. *Cakile maritima* is another halophyte from Tunisia studied in some details (Ghars et al., 2005), where different accessions have been reported to contain 25.4–38.8% oil but because of the presence of 25–35% erucic acid, the oil was appropriate only for industrial application and unfit for human consumption.

The actual yield (and the yield potential) of halophytes remains largely unknown because of absence of their domestication. They grow in areas of variable salinity and regimes. One thing appears certain that these plants will tolerate extremely harsh conditions. Isolated field studies with *Salicornia europaea* in Mexico, Egypt, and United Arab Emirates reported a production of 20 tons of total biomass per hectare, with a yield of two tons of seeds (Goodin, et al., 1990). Glenn et al. (1991) also reported similar yields with *S. bigelovii*. While such reports are encouraging, actual yield in a commercial set up would probably be much lower and would require considerable energy imput. From a new use point of view, the production would involve perennial plants that use brackish water.

An important aspect is the oil quality, which is related to its degree of unsaturation. Oil with high unsaturation is considered healthier (USDA, 1990; Lang, 1997). Unsaturation in the seeds of various halophytes e.g. species of *Suaeda*, *Atriplex*, *Halogeton*, *Kochia*, *Allenrolfea,* and *Sarcobatus* have been reported to range from 78% to 89% (Weber et al., 2001). He et al. (2003) also reported that seeds of *Kosteletzkya virginica* were composed largely of unsaturated fatty acids, high potassium, and low sodium. The above data compare well with 74% unsaturated fatty acids present in the oil of *S. fruticosa*. The oil of other halophytes under study, except that from *A. maurorum*, was at least 70% unsaturated and hence, appeared suitable from a health point of view. The oil from *A. maurorum* (45% unsaturation) however, was comparable with palm oil which is 52% saturated. However, Fodder from *A. maurorum* is highly palatable to animal especially small ruminants, and could be a rich source of energy providing fodder for them.

While assessing the quality of edible oil, individual lipid fractions have also to be taken into consideration before making any recommendations. High level of erucic acid ($C_{22:1}$) exceeding 25% for instance, is not considered fit for animal or human consumption (Cherif et al., 1992). The oil from the seeds of the halophytes studied was free from any such undesirable component and could safely be recommended for human consumption.

Oil from the halophytes in this study was almost similar in composition (not necessarily the quantities) with respect to individual fatty acids of commercial oils. While canola (Declercq and Daun, 1998) and olive oil (Zarrouk et al., 1996) have very low palmitic acid ($C_{16:0}$) and are dominated by monounsaturated oleic acid ($C_{18:1}$), the fatty acid fractions present in all the halophytes i.e. high linoleic acid ($C_{18:2}$) is generally comparable with oil crops like sunflower (Karleskind, 1996) or cotton (Smaoui and Cherif, 1992).

The halophytic seeds were initially reported as free from inorganic ions (Ungar, 1991), however, later data on the perennial halophyte showed that the ash content could be as high as 35% (Khan and Ungar, 1996b). Our data showed a mix pattern in the species with *H. mucronatum* and *A. marorum* having little ash content (4%) followed by *S. fruticosa* and *C. cretica* with 7% ash, while seeds from *H. stocksii* (20%) and *A. macrostahyum* (35%) showed that a significant amount of their dry weight is actually ash. The pressed cake left after oil extraction, is a valuable by-product used in cattle feed. The high quantities of macro- and micro-nutrients present in halophyte seeds present an opportunity to explore the use of their pressed cake as animal feed.

Preliminary studies of oilseed of local halophytic species validate the hypothesis that their oil quality is comparable with conventional edible oils such as those from sunflower and canola. These crops could be grown with brackish water.

References

Anonymous, 1995. The Cyclopedia of Chinese Medicine-Basic Medicine. Science and Technology Publishing Company, Shanghai, China, pp. 393–395.

Anonymous, 2005. Agricultural Statistics of Pakistan, 2003–2004. Ministry of Food, Agriculture and Livestock, Government of Pakistan, Islamabad.

Bashan, Y., Moreno, M., Troyo, E., 2000. Growth promotion of the seawater irrigated oilseed halophyte *Salicornia bigelovii* inoculated with mangrove rhizosphere bacteria and halotolerant *Azospirillium* spp. Biological Fertle Soils 32, 265–272.

Cherif, A., Ben Miled, D., Marzouk, B. Smaoui, A., Zarrouk, M. (Eds.), 1992. Metabolism, Structure and Utilization of Plant Lipids. CNP, Tunis. pp. 341–343.

Declercq, D.R., Daun, J.K., 1998. Quality of 1997 Ontario Canola. Final Report. Grain Research Laboratory, Winnipeg, Manitoba, Canada: Canadian Grain Commission.

FAO, 2005. Global Network on Integrated Soil Management for Sustainable Use of Salt-affected Soils.

Ghars, M.A., Debez, A., Smaoui, A., Zarrouk, M., Grignon, C., Abdelly, C., 2005. Variability of fruit and seed oil characteristics in Tunisian accessions of the halophyte *Cakile maritima* (Brassicaceae). In: Khan, M.A., Weber, D.J. (Eds.), Ecophysiology of High Salinity Tolerant Plants. Springer, The Netherlands, pp. 55–67.

Glenn, E.P., O'Leary, J.W., Watson, M.C., Thompson, T.L., Kuehl, R.O., 1991. *Salicornia bigelovii* Torr: an oil seed halophytes for sea water irrigation. Science 251, 1065–1067.

Goodin, J.R., Epstein, E., McKell, C.M., O'Leary, J.W., 1990. Saline Agriculture, Salt Tolerant Plants for Developing Countries. National Academy Press, Washington, DC, 143pp.

Gulzar, S., Khan, M.A., 1998. Diurnal water relations of inland and coastal halophytic populations from Pakistan. Journal Arid Environments 40, 295–305.

He, Z., Ruana, C., Qin, P., Seliskar, D.M., Gallagher, J.L., 2003. *Kosteletzkya virginica*, a halophytic species with potential for agroecotechnology in Jiangsu Province, China. Ecological Engineering 21, 271–276.

Hu, F., 1997. Dietary fat intake and the risk of coronary heart diseases in women. New England Jouranl Medicine 337, 1491–1499.

Jafri, S.H.M., 1966. Flora of Karachi (Coastal West Pakistan). University of Karachi, Karachi, Pakistan, pp. 45–46.

Karim, A., Qadir, S.A., 1979. Phytosociological studies of the coastal swamps of Karachi. Bangalore Journal of Botany 4, 89–98.

Karleskind, A., 1996. Oils and Fats Manual, a Comprehensive Treatise, vol. I. Lavoisier Publishing, 806pp.

Khan, M.A., Aziz, S., 1998. Some aspects of salinity, plant density and nutrient effect on *Cressa cretica* L. Journal of Plant Nutrition 21, 769–784.

Khan, M.A., Ungar, I.A., 1996a. Influence of salinity and temperature on germination of *Haloxylon stocksii* Bunge ex. Boiss. Annuals Botany 8, 547–551.

Khan, M.A., Ungar, I.A., 1996b. Comparative study of chloride, calcium, magnesium, potassium and sodium content of seed in temperate and tropical halophytes. Journal of Plant Nutrition 19, 517–525.

Lang, L., 1997. Types of Dietary Fat: Key to Heart Risk. Reuters Health Information Services, Inc.

Mandal, S., Yadav, S., Singh, R., Begum, G., Suneja, P., Singh, M., 2002. Correlation studies on oil content and fatty acid profile of some Cruciferous species. General Research of Crop Evolution 49, 551–556.

O'Leary, J.W., Glenn, E.P., Watson, M.C., 1985. Agricultural production of halophytes irrigated with seawater. Plant and Soil 89, 311–321.

Parida, A.K., Das, A.B., 2005. Salt tolerance and salinity effects on plants: a review. Ecotxicological Environment Safety 60, 324–349.

Smaoui, A., Cherif, A., 1992. Glycerolipids in salt stressed cotton seeds. In: Ungar, I.A. (Ed.), Ecophysiology of Vascular Halophytes. CRC Press, Boca Raton, FL.

Stewart, R.R., 1972. An annotated catalogue of the vascular plants of West Pakistan and Kashmir. In: Nasir, E., Ali, S.I. (Eds.), Flora of Pakistan. Department of Botany, University of Karachi, Karachi, Pakistan, pp. 1–1028.

USDA. 1990. Composition of foods: fats and oils—raw, processed, prepared. Agriculture Hand Book 8-4, Beltsville, MD, USA.

Weber, D.J., Gul, B., Khan, M.A., Williams, T., Wayman, P., Warner, S., 2001. Comparison of vegetable oil from seeds of native halophytic shrubs. In: Mc Arthur, E.D., Fairbanks, D.J. (Eds.), Proceeding of Shrubland Ecosystem Genetics and Biodiversity. RMRS-P-21. USDA Forest Service, Ogden, UT, Rocky Mountain Research Station, USA, pp. 287–290.

Yajun, B., Xiaojing, L., Weiqiang, L., 2003. Primary analysis of four salt tolerant plants growing in Hai-He plain, China. In: Leith, H., Mochtchenko, M. (Eds.), Cash Crop Halophytes: Recent Studies. Kluwar Academic Publishers, London, Great Britain, pp. 135–138.

Zarrouk, M., Marzouk, B., Daoud, B., Cherif, A., 1996. Oil accumulation in olives and effect of salt on their composition. Olivae 61, 41–45.

Zarrouk, M., El Almi, H., Ben Youssef, N., Sleimi, N., Smaoui, A., Ben Miled, D., Abdelly, C., 2003. Lipid composition of seeds of local halophytes: *Cakile maritima*, *Zygophyllum album* and *Crithmum maritimum*. In: Leith, H., Mochtchenko, M. (Eds.), Cash Crop Halophytes: Recent Studies. Kluwer Academic Publishers, London, Great Britian, pp. 121–124.