Kochia (*Kochia scoparia* (L.) Schrad) Unwanted or Wanted Plant for Forage Production in Harsh Environments

Mohammad Kafi, Bilquees Gul, and Masoumeh Salehi

Abstract

Kochia (*Kochia scoparia)* have recently been considered as forage and fodder crop in marginal lands. Under severe drought and salinity kochia (35 dS m^{-1}) could produce up to 16 and 8 t DM ha^{-1} biomass in spring and summer cropping, respectively. Kochia produce 90 % biomass at 75 % water application in comparison to 100 % water application. Therefore, deficit irrigation is a useful management technique for Kochia even under saline conditions. Seeds of Kochia can germinate in a wide range of temperature, different levels of water potential, salinity, pH and depth of flooding and showed a high recovery from stress condition. Quick germination and growth of Kochia and its desirable drought, salinity and extreme temperature tolerance indicate that it can be considered as a valuable forage plant in case of shortage of conventional forage occurs, particularly in arid and semiarid regions. Cultivation of Kochia using saline waters for rehabilitation of saline areas, that have been left barren, can be regarded as an approach in sustainable and low-input agriculture. Biomass and seeds of Kochia can help in food production for people settled in these regions and their animals. Kochia in addition to be a forage crop can also be used bioremediation, oilseed and biofuel crop.

1 Introduction

Drought and salinity are the most important environmental factors inhibiting photosynthesis and decreasing growth and productivity of plants in many parts of the world. Therefore, extensive research into plant salt and drought tolerance has been carried out, to recognize or improve the tolerance of conventional crops as well as other capable plants [1]. Majority of the world's population relying on crops such as wheat, maize and rice to survive, evaluation and improvement of

M. Kafi (✉)
Department of Agronomy and Plant Breeding, Ferdowsi University of Mashhad, Mashhad, Iran
e-mail: mkafi36@yahoo.com

B. Gul
Institute of Sustainable Halophyte Utilization (ISHU), University of Karachi, Karachi 75270, Pakistan
e-mail: ishu_gul@yahoo.com

M. Salehi
National Salinity Research Center, Yazd 89471-73847, Iran
e-mail: salehimasomeh@gmail.com

M.A. Khan et al. (eds.), *Sabkha Ecosystems: Volume IV: Cash Crop Halophyte and Biodiversity Conservation*, Tasks for Vegetation Science 47, DOI 10.1007/978-94-007-7411-7_11,

these crops salt tolerance are globally important. The result of many experiments shows that salt tolerance of above mentioned crops is limited to less than 10 dS m^{-1} [1].

There are as many as 6,000 species of terrestrial and tidal halophytes in the world [2]. In Iran, presently, a total of 365 species belonging to 151 genera and 44 families are known to grow in salty habitats, but they might be more than 400 species [3]. This group of plants tolerate salt concentrations that kill 99 % of glycophyte species [4].

Water is one of the essential resources in arid and semi-arid regions, where one-sixth of the world population lives [5]. In areas with water shortage, an attractive option is using seawater or brackish water for crop production, and this has worked well in inland and coastal sandy soils of some desert environments. Saline water aquifers and underground water sources exist in many arid lands of the world but these have been greatly underutilized. This brackish water could be a major resource in saline agriculture to produce food, feed, and fiber and oil seeds on non-productive, saline arid lands. In further support of saline agriculture, there would be no shortage of water since seawater in the oceans makes up 97 % of water on earth. Desert land is also plentiful, with around 43 % of the earth's total land surface being arid or semi-arid. A small part of this (about 15 %) is close to the sea and this would be convenient for growing crops using saline agriculture. There are hundreds of halophytes with characteristics to be used as cash crops. Saline agriculture, however, must fulfill two conditions to be cost-effective. First, it must produce useful crops at yields high enough to justify the expense of pumping salty water. Second, researchers must develop successful agronomic techniques for growing saline, water-irrigated crops in a sustainable way. These methods must also not contribute to further damage of natural environments. If applied successfully, this approach would lead to the domestication of wild, salt tolerant plants for use as food, forage, and oilseed crops. It was estimated that about 2,500–3,000 plant types occur naturally in saline habitats [6].

The most agriculturally useful halophytes are those that combine the attributes of efficient water use with high quality biomass production. Some halophytes used for millennia as forage species in arid and semi-arid areas. These species can support animal production provided they are grown in combination with less saline herbage such as legume species [7].

In the background of the progressive shortage of fresh water resources and soil salinization, a major aim is to evaluate the potential of local (xero-) halophytic species to be widely and economically used in arid and semi-arid regions. Major research topics are to identify and select plant species tolerant to drought and salt stress, to study their potential in the field of human or animal nutrition and to evaluate the possible use of non-conventional waters, such as seawater, brackish water and pre-treated wastewater. One possible concept of sustainable agriculture is based on "cash crop halophytes" irrigated with saline waters up to seawater salinity [8]. Scientists have conducted research on Kochia (*Kochia scoparia)* as a salt, drought and high temperature cash crop, that we will summarize them in the following sections.

2 Botany

Kochia (*Kochia scoparia)* is native to central and Eastern Europe and western Asia. It is well-adapted to arid conditions because of its deep root system. Penetration depths up to 5 m; lateral roots can extend to a horizontal distance of 7 m. The extensive taproot system and ball-like shoot mass that acts as tumbleweed are key morphological features that aid Kochia colonization or survival [9].

It is an annual herb, bushy to pyramid shaped, 0.15 to over 2 m tall; taproot up to 5 m long. Stems erect, green or red-tinged, much-branched, round, slender, soft-hairy or smooth; shoot breaks off at ground level forming a ball-like mass that acts as tumbleweed when mature and dry. Leaves are simple, alternate, sessile, narrow-linear to lanceolate, 1.5–6.0 cm long, tapering to a point at the tip, margins entire and fringed with hairs, pale green, upper surface usually smooth, lower surface usually covered with soft hairs; leaf blades with three or five prominent veins, leaves of the main stem larger than those of the branches, becoming progressively smaller along the branches toward the tips, often turning purplish-red in autumn. Flowers are inconspicuous, small, apetalous five-lobed calyx, sessile, green; solitary or clustered in groups of two to six in axils of upper leaves and dense bracted spikes. Sepals are spineless, with a short, wedge-shaped, scarious wing in fruit, sometimes surrounded by a cluster of long hairs; bracts linear lanceolate, attenuate, acute or acuminate, greenish. Flowers either perfect (three to five stamens) or pistillate (lacking stamens); ovary undivided, ovoid, single-seeded with the pericarp free from the seed.

Seeds nearly oval, ca. 1.5–2.0 mm long, flattened, grooved on each side, surface dull, brown with yellow markings to dark reddish-brown to black, covered by a thin papery envelope, and often enclosed by a fragile star-shaped hull (the attached flower parts) (Fig. 1). Kochia is diploid with a somatic chromosome number of 2n = 18 [9].

3 Reproduction

Kochia is self-compatible and produces protogynous flowers where the stigmas emerge before anther development [13, 14]. The stigmas usually emerge 1 week before pollen is shed, are receptive to foreign pollen during that time, and deteriorate before anther dehiscence which prevents self-pollination in the same flower [14]. Pollen grains are spherical, and granular with 100–130 pores uniformly distributed over the grain surface [14].

It is estimated that 0.1 % of shed pollen would be distributed more than 150 m from the source [15]. Wind is an important pollination vector, but bees (Colletidae and Halictidae) also contribute to cross pollination in Kochia [16]. Kochia biotypes or ecotypes can show large variability in days to flowering, which may affect synchrony of pollination. In a field study in North Dakota. The reported time from emergence to flowering among 13 Kochia accessions collected from across the western USA varied from 57 to 100 d [17]. Two Kochia biotypes from North Dakota, which differed markedly in plant structure, also differed in time to flower initiation by as much as 24 d [14].

4 Ecology of Kochia

The ability of Kochia to establish quickly and grow vigorously under harsh environments allows it to become an important colonizer. It was non-existent in the forests, while it occurred in 45 % of the grain field and 17 % of the rangeland observed. A field study of Canadian prairies showed that Kochia was present in 45 % of all saline areas surveyed [18]. Kochia was one of the most common species occurring in dry land saline areas.

4.1 Soil Condition

Kochia germinated well over a wide pH range [19]. Germination was slightly reduced at pH extremes of 2 and 12 when compared to intermediate acidities. Kochia was thus shown to germinate in acidic to alkaline soils. Kochia seedlings had shorter radicles and hypocotyls at pH 2 than those at pHs between 3 and 10 [20]. Hypocotyls become shorter as the pH raised above 10. Germination percentage was approximately 50 % even in acidity of 4 and alkalinity of 9 solutions [21].

Much like any other plant, moisture is required by Kochia for germination and establishment. Germination of Kochia was not significantly reduced until the osmotic potential of the growth medium reached −8 bars. Germination declined as the potential decreased from −8 to −10 bars; even at −16 bars, Kochia still had 50 % germination, showing that soil moisture stress had no severe effect on germination [22].

Dry matter yield and root dry matter raised in a linear fashion as Nitrogen (N) application was increased from 0 to 250 kg ha^{-1} [23]. Phosphorous (P) fertilization also increased dry matter yield. Interactions were observed between N and P levels and the resulting dry matter yields. N at lower levels tended to have a greater yield

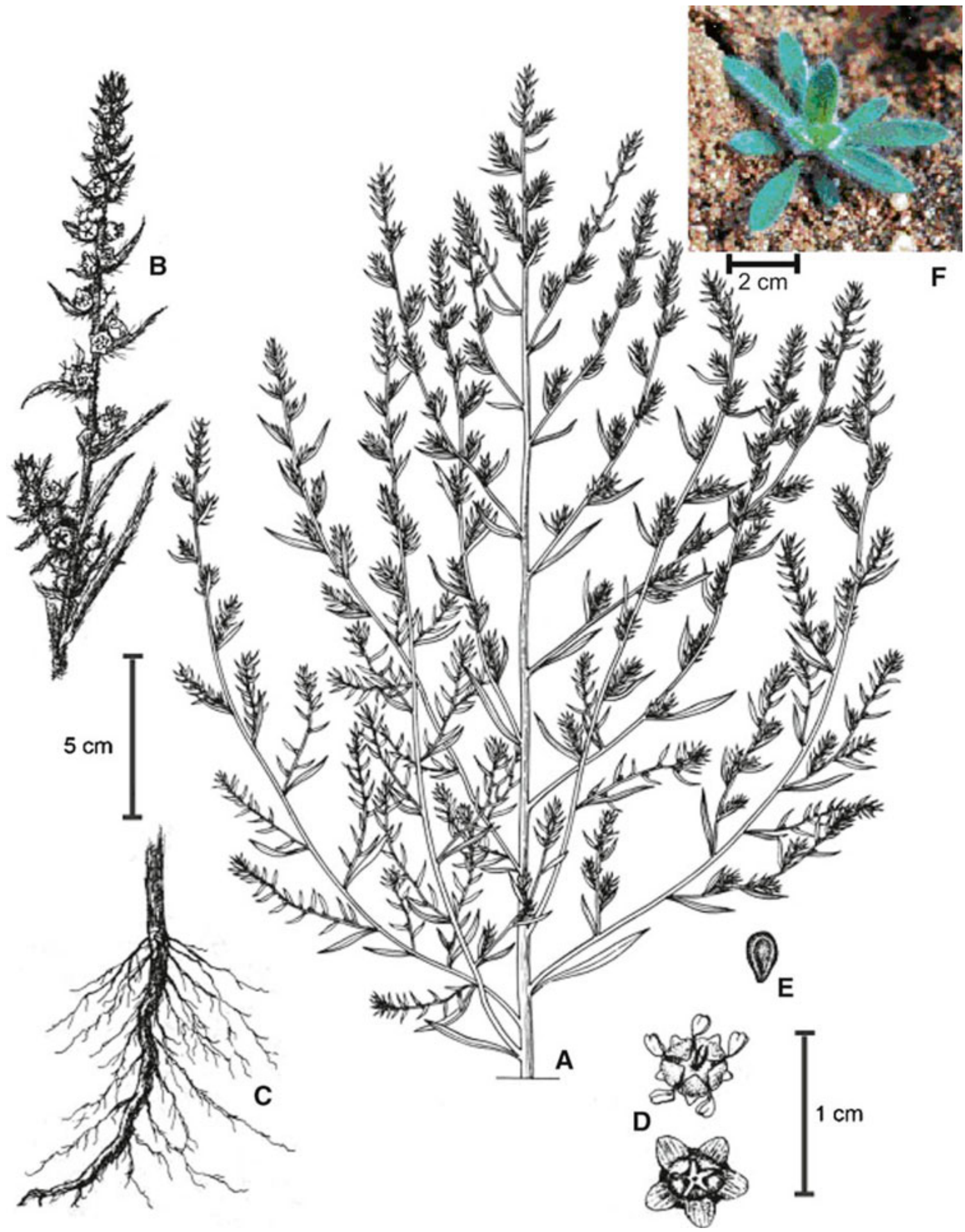


Fig. 1 *Kochia scoparia* (modified from [10, 11]: *A* mature plant; *B* upper branch; *C* root; *D* flowers; *E* naked/bare seed; *F* seedling [12])

increases. Whether N fertilization may hasten the plant maturity is still debatable. The effect of fertilizer on Kochia yield is previously reported in literature [24]. This experiment was conducted outdoors in pots buried in the ground. From the first 48 ppm of N added, a 3 fold increase in yield was obtained. Subsequent additions of N gave further yield increase. Plant color is the possible method for approximating the soil fertility.

Fertilization may become important with continuous Kochia cropping on the same site because an 8 t ha^{-1} yield with 12.5 % crude protein would remove about 160 kg N ha^{-1}[24]. In field trials, adding fertilizer gave substantial yield increases

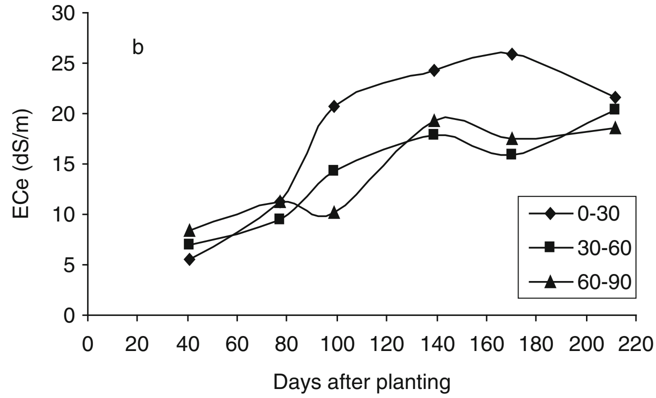


Fig. 2 Salinity variation (dS m^{-1}) of soil depth in Kochia farm as a function of days after planting at 28 dS m^{-1} and 100 % water application

judging by taller, darker green plants compared to the control.

The effects of various levels of phosphorus and nitrogen fertilizer was evaluated in irrigating condition with salt water on forage characteristics of Kochia by applying two levels of salinity of irrigating water (5.2 and 16.5 dS m^{-1}), and three nitrogen levels in the form of urea (0 (control), 100, 200 kg h^{-1}) and three phosphorus levels in super phosphorus form (0, 100, 200 kg h^{-1}) [25]. The results showed that nitrogen application leads to increase in height, lateral shoots, green area index and the leaf to stem ratio, fresh and dry biomass production compared with control. Phosphorous did not have any significant effect of forage parameters. The interactions of salt and nitrogen showed that nitrogen can partially decrease the negative effects of salt stress on Kochia and improve the forage characteristics and biomass production.

Evaluating the electrical conductivity of the saturated soil extract (ECe) in spring cropping showed that the soil salinity increased with saline water application [26]. The highest salt accumulation was observed at a depth of 0–30 cm of top soil at all levels of salinity. Soil salinity rose with saline water. For establishing Kochia, adequate leaching water must be applied for a proper stand, especially at 28 and 35 dS m^{-1}. Saline water up to 10 dS m^{-1} did not have a considerable effect on the Kochia seed germination [27]. But, after crossing this threshold the germination percentage and the rate decreased significantly and extreme reduction occurred at 20 dS m^{-1} salinity, but adequate rainfall leached the soil salinity from the top soil, thereby allowing Kochia a good opportunity to emerge fast in the existing conditions (Fig. 2).

4.2 Temperature

High growth of Kochia correlated closely with soil temperature with a base of 10 °C [28]. Low temperature is one of the most important environmental factors limiting the growth, product and geographical distribution of plants. A study carried out in three successive research phases to evaluate some agronomic, morphologic, biochemical and physiological traits of Kochia in different temperature conditions to assess the cold and freezing tolerance Kochia by using of pacloputrazol, hexaconazole and penconazole (0, 10 and 20 mg L^{-1}) and after that treated by freezing temperatures 0, −2, −4, −6 and −8 °C. Result showed that increase fungicide concentration in 10 and 20 mg L^{-1} than control decreased electrolyte leakage but electrolyte leakage build-up with decrease freezing temperature. Fungicide application increased −2 °C freezing tolerance in Kochia. Results showed that by reducing the temperature to −9 °C, electrolyte leakage remained constant and reducing the temperature below −12 °C caused a sharp increase in electrolyte leakage. Proline, soluble carbohydrates, total phenol concentration and electrolyte leakage decreased with increase in paclobutrazol concentration.

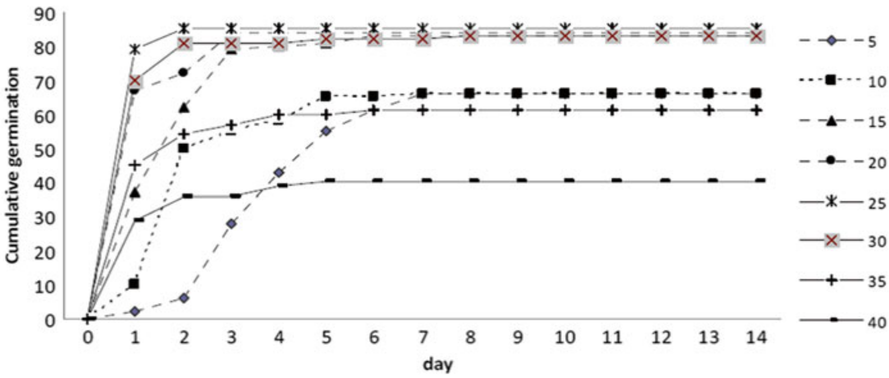


Fig. 3 Kochia cumulative germination at different temperature treatments during 14 days [21]

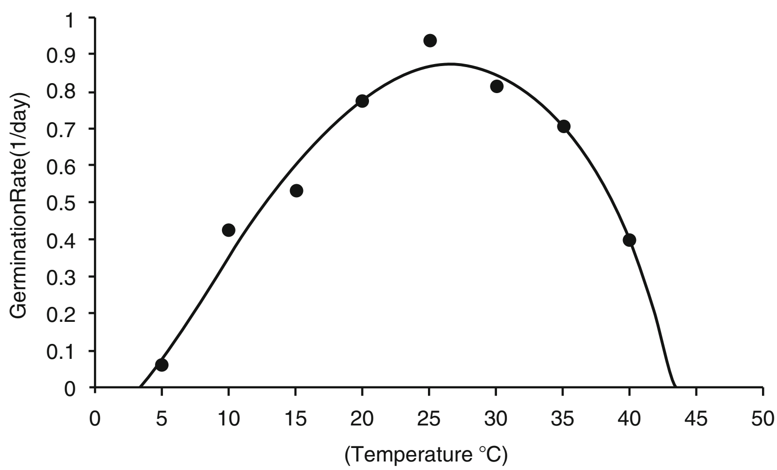


Fig. 4 Temperature and germination rate relationship in Kochia (to evaluate cardinal temperature) $R^2 = 90$ [21]

Germination characteristic of Kochia was evaluated at 5, 10, 15, 20, 25, 30, 35 and 40 °C under dark germinator showed that the highest germination percentage was obtained at 20–30 °C and the lowest obtained at 40 °C (Fig. 3) [29]. The longest and shortest period to 20 and 50 germination percentage was recorded to 5–10 °C and 20–30 °C respectively. Based on Five-Parameters Beta model, base, optimum and ceiling temperature for Kochia estimated 4 °C, 22.1 °C and 41.2 °C respectively (Fig. 4).

Kochia seeds were germinated in temperature regime of 25 °C night and 35 °C day yielded maximum germination [6]. Cooler temperature 5–15 °C significantly inhibited seed germination. Germination rate was highest at 25–35 °C and lowest at 5–15 °C, respectively. Previously reported that from 8 to 35 °C, average germination percentage was 85 %, but when temperature increased to 40 °C, germination percentage decreased to 31 % [30]. Although in 25 °C time taken to 50 % germination was achieved only at the first 24 h, when temperature increased or decreased from this level, germination rate decreased. Based on results, Kochia can adjust its germination in a wide range of temperature, from 3.5 (T_{base}) to 50 °C (T_{max}), with optimum germination temperature of 24 °C. This extended temperature range of Kochia germination and its ability of rapid germination reflect high potential of this plant to establish in most areas of Iran, as a new forage crop.

5 Water Requirement (Quantitatively and Qualitatively)

Kochia is responsive to water application but it can tolerate in the drought condition by reducing the transpiration surfaces. It is a halophyte, so that it can produce biomass in the presence of salinity. In an experiment arranged by Salehi [31], the effect of salinity on the shoot dry biomass was significant but interaction of drought and salinity effects were not significant in spring cropping [32].

The results of summer (first of June up to the end of September) and spring (first of April up to the end of September) cropping showed that increasing water application above the field capacity did not increase the salt tolerance level of Kochia [31]. It was found that the plant response to salinity depends largely on the soil water regimes [33]. Water and salt stress may have an additive effect in depressing the plant growth [34, 35]. The salinity tolerance level of Kochia could be improved by increasing water application. The highest and the lowest salt tolerance indices of Kochia were observed at 100 % and 50 % water application, respectively. Shortening the irrigation interval in saline conditions has the same benefit as shortening the irrigation interval in non-saline conditions [34]. It is predicted that the effects of salt stress may be ameliorated by more water [36]. However, in contrast it is reported that, the critical irrigation level decreased with increasing salinity, there by demonstrating that additional water does not compensate for salt stress [37]. The highest shoot biomass harvested at 1.5 dS m^{-1} treatment, in spring cropping (Table 1).

Table 1 Shoot dry biomass of Kochia irrigated with 6 levels of saline water and different levels of water application in 2008 (summer cropping), and 2009 (spring cropping), respectively

	Year	
	Summer cropping	Spring cropping
Salinity	Shoot dry biomass (g m^{-2})	
1.5	1342.1 a	3439.6 a
7.0	1393.9 a	2955.1 ab
14	1193.8 ab	2701.2 bc
21	1013.9 bc	2321.4 c
28	1017.4 bc	2199.6 c
35	883.1 c	1592.0 d
Irrigation		
50 %	1098.41 B	2572.4 A
75 %	1053.26 B	2714.2 A
100 %	1270.48 A	2573.6 A
125 %		2279.1 A

Shoot dry biomass followed by the same letter are not statistically different according to the least significant differences (*LSD*) between all pairs at the α-probability of 0.05. Irrigation levels compared separately [31]

In summer cropping, the highest shoot biomass was obtained at 7 dS m^{-1}. Under severe drought and salinity, Kochia still could produce 16 t DM ha^{-1} biomass spring cropping and 8 t DM ha^{-1} biomass in summer cropping, respectively (Table 1). Maximum biomass production of Kochia was 34 and 14 t DM ha^{-1} for spring and summer cropping at the mid bloom stage, respectively. Kochia produced 11 t DM ha^{-1} of dry matter in the Khorasan province of Iran [38]. Kochia production in Texas under dry condition and under irrigation was 11.3 t DM ha^{-1} and 26 t DM ha^{-1}, respectively [39, 40]. Kochia produced remarkable biomass in north of Iran.

In order to evaluate crop coefficient of Kochia in different salinity treatments; growing period of Kochia divided to four stages (Fig. 5). With increasing salinity crop coefficient reached to its maximum later and dropped earlier that indicate lower water requirement under salinity stress [31]. Salinity effect was evaluated on safflower water use and expressed that water consumption decreased with increasing salinity [41]. Reduction in crop coefficient may slow plant growth, lack of full coverage of canopy and lower evapotranspiration [42]. Salinity reduces growth, turgor pressure and so reduces water absorption [42].

Crop coefficient of Kochia in Birjand was 1.2 in its highest water consumption [27]. In fact plant height, leaf and soil albedo, canopy resistance and evaporation from soil can effect on determination of crop coefficient.

Optimal conditions for germination and recovery of germination from saline condition (0, 200, 400, 600, 800 and 1,000 mM NaCl) were

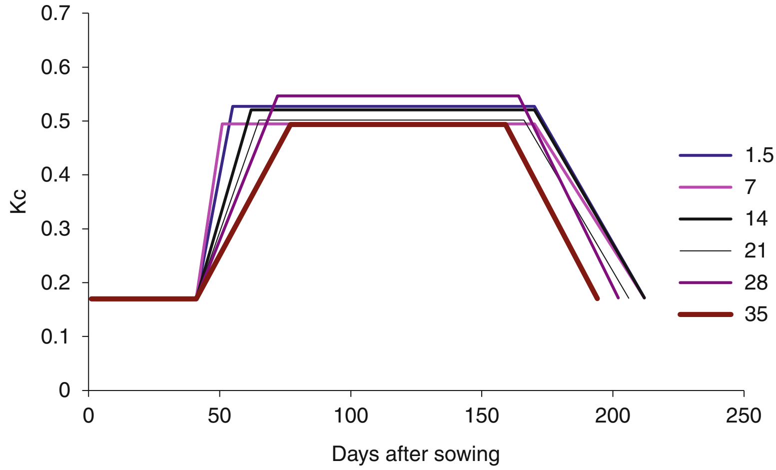
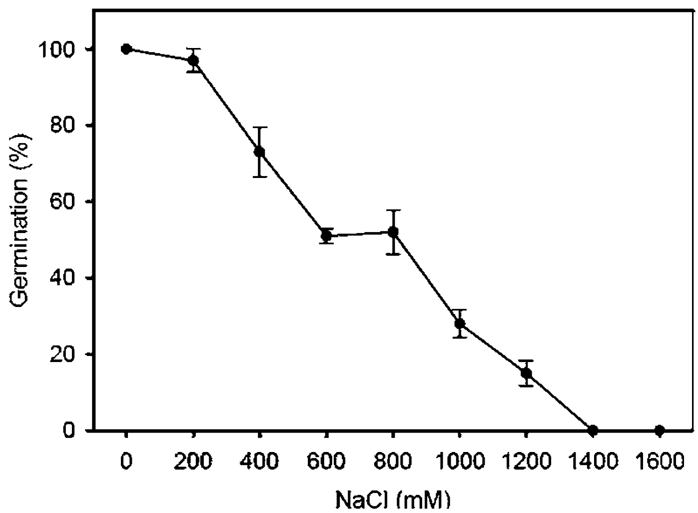


Fig. 5 Crop coefficient of Kochia at six levels of saline water in spring cropping [31]

Fig. 6 Seed germination (Mean ± S.E.) of *Kochia scoparia* under various concentrations of NaCl at 25–35 °C [43]



determined after being transferred to distilled water and reported that maximum germination occurred in distilled water, and an increase in NaCl concentration progressively inhibited seed germination [6]. Seeds were transferred from salt solutions to distilled water after 20 days and those from high salinities recovered quickly at warmer temperature regimes. Final recovery germination percentages in high salt treatments were high; indicating that exposure to high concentration of NaCl did not inhibit germination permanently.

The effects of salinity on germination, growth, ion accumulation and water relations of *Kochia scoparia,* was studied under greenhouse conditions and found that it is tolerant to salinity (600–800 mM NaCl) at germination; the seedling growth remained unaffected up to 600 mM NaCl and the plants survived with reduced growth up to a high salinity of 1,800 mM NaCl (Fig. 6) [43].

The germination characteristic of Kochia under different levels of salinity (0, 5, 10, 15, 20, 25, 30, 35 and 40 dS m^{-1}) using NaCl was evaluated and reported that the highest percentage of germination was in distilled water that didn't show any significant effect with 5 and 10 dS m^{-1} [21]. By increasing salinity, dry weight and length of seedling decreased. Potential of forage production of five different Kochia ecotypes in response to different levels of salinity

(5.2, 16.5 dS m^{-1}) in five Kochia ecotypes (Birjand, Urmia, Borojerd, Esfahan and Sabzevar) was investigated and showed that in the highest level of salinity, dry and fresh forage yield was comparable with low level of salinity and all Kochia ecotypes tolerates against these levels of salinities [44].

5.1 Disease

Kochia seedlings are susceptible to damping off. The causal organism of this disease was identified as Pythium de Baryanum. Attack of the disease occurred during and after seedling emergence. Discoloration of seedlings and collapse of the axis tissues were evident and the affected plants died. Leaf spot diseases attacked Kochia plants 3–6 in. high in nursery plots. The spot symptoms on leaves frequently became extensive enough to kill leaves. Stand destruction was a threat during cool rainy periods which are favorable to the spread of the disease [22] Kochia did not have diseases in Iran.

6 Cultivation Practices

6.1 Seeding Density and Depth

Emergence of Kochia averaged 74 % when seeds were left on the soil surface and it was reduced to 57 % when seeds were planted at a 3 mm depth. Maximum planting depth was 5 cm from which Kochia could successfully emerge. Since germination was unaffected by the absence of light, the decrease in emergence from depth was attributed to small seed size [22]. If Kochia is grown in stands of high density, primary axis growth is vigorous while lateral branch growth is suppressed resulting in tall, linear to lancelet shaped plants.

Kochia seed can germinate in a wide range of temperature, different levels of water potential, salinity, pH and depth of flooding and have a high recovery from stress condition. To obtain basic information from Kochia seed, result showed that the highest total germination and germination rate was observed in 20–25 °C. Hydropriming for 4 and 8 h cause decreasing in percentage, rate and germination index but increase in mean germination rate [29]. Increasing in flooding period caused decreasing in germination percentage compared to control. Electrolyte leakage increased with increasing in flooding [29].

Maximum forage yield was obtained from full irrigation with 13.22 t ha^{-1} dry matter and 31.81 t ha^{-1} fresh materials in Khorasan province [45]. In 40 % treatment a significant reduction in oil percentage (33 %) and seedling dry weight (65 %) were observed to complete irrigation.

The highest biological yield, leaf and stem dry weights and protein yield were obtained at 30 plant m^{-2} [46]. The best plant density, in terms of biomass production and leaf and stem dry weight, yield of protein was obtained at 30 plant m^{-2}, while for grain production a plant density of 20 plant m^{-2} could be recommended (Fig. 7).

Effect of salinity on seed yield was significant but the effect of water stress was not significant; however, salinity effect depends on the amount of water application. There were no significant differences in biomass production at 75, 100, and 125 % water requirement application but the effect of salinity was significant at 50 % water requirement application (Table 2). The highest seed yield was observed at 75 % water requirement application, 1.5 dS m^{-1} with 2.3 t ha^{-1} and the lowest seed yield was observed at 50 % water requirement application, 42 dS m^{-1} with 1.5 t ha^{-1}. In summer cropping kochia could produce 3.3 t ha^{-1} seed and at 35 dS m^{-1} produced 1.6 t ha^{-1} in the north of Iran. Kochia seed yield at full irrigation was 2.8 t ha^{-1} and reduced significantly at 80 % water requirement application in Kohorasan province [38]. It seems that the response of seed production to water requirement is dependent on the climate condition and sowing time.

7 Special Characteristics of Kochia

7.1 Drought Tolerance

Water potential measurements on Kochia plants showed a unique situation in which the potentials became and remained low even under irrigation [47].

Fig. 7 Kochia in a field trail [31]

Table 2 Effect of saline water and water application on seed production of Kochia in spring cropping

Salinity (dS m^{-1})	Water application (%)			
	50	75	100	125
	Seed yield (g m^{-2})			
1.5	231.00 a	229.09 a	251.14 a	279.27 a
7	272.24 ab	265.68 a	231.83 a	237.81 a
14	267.22 a	228.32 a	240.60 a	235.56 a
21	186.85 ab	181.94 a	210.55 a	229.01 a
28	194.05 ab	187.50 a	178.24 a	182.03 a
35	188.71 a	163.05 a	173.15 a	173.06 a
42	154.38 b	179.67 a	158.14 a	209.91 a

Seed yield followed by the same letter for salinity levels within each water application level are not statistically different according to the least significant differences (LSD) at α-probability of 0.05 [31]

Plants may show drought avoidance by one or more adaptation strategy. One adaptation is more vigorous and competitive root system which gives the plant access to more soil moisture by using a greater volume of soil. A second adaptation involves using a specialized, highly efficient photosynthetic pathway [22]. A series of experiments using different levels of saline water (1.5–42 dS m^{-1}) and different levels of applied water (25–125 % of the water requirement) in the farm and greenhouse was performed [31]. Results showed that Kochia like other halophytes is sensitive to drought and salinity at the earliest stages of growth. Salinity reduced linear phase of growth and decreased biomass production but salinity tolerance of Kochia was improved by increasing water application. Plants showed more tolerance against drought stress, when stress was induced in the whole growth season. In all experiments, ecotypes from the arid regions, revealed a better response to drought and salinity. Under severe drought and salinity, Kochia still could produce up to 16 and 8 t DM ha^{-1} biomass. Results of water depletion from different soil layers showed that Kochia uptakes more water from the 30–60 cm soil depth. The soil salinity (ECe) of this section was lower in comparison to the 0–30 cm soil depth. At 75 % application of water requirement, Kochia produced 90 % of biomass in comparison to 100 % water application. Therefore, deficit irrigation is a useful management technique for Kochia even under saline conditions.

7.2 Salt Tolerance

Kochia is very tolerant to salinity. It is so salt tolerant that only 50 % seed yield reduction occurred at 35 dS m^{-1} of irrigation water [26] and 50 % reduction of plant dry weight was calculated at 38.16 ± 3.53 dS m^{-1}. Using 7 dS m^{-1} of saline water and 50 % of water requirement application will cause only 13 % reduction in seed yield. The interaction effects of salinity and drought might not be additive or multiplicative and it might be even ameliorative. Plants under salinity stress will produce less transpiration area (leaves), so plant can manage drought more efficient. Drought might limit the water in the surface layer of the soil so that plants will send their roots to the deeper soil layers and the salt concentration at that layer might be lower than upper layers.

7.3 Rooting Habit

An investigation was undertaken at Hays, Kansas to study the root system of Kochia [48]. In first experiment, Kochia roots had penetrated to a depth of at least 2.4 m, but considerable lateral branching was also apparent. Kochia had a rooting profile of 6.7 m wide and more than 2 m in depth [49]. From such investigations, it appears that the rooting habit of Kochia is important in its drought resistance.

7.4 C4 Photosynthetic Pathway

Kochia is a C_4 plant that uses NADP-ME in the C_4 photosynthetic pathway [50], and displays a kochioid type of C_4 Krantz anatomy [51, 52]. A specific feature of such C_4 pathway is the requirement for sodium (Na) as a micronutrient [53]. Sodium may have a physiological role in enhancing in vivo activity of the C_4 enzyme phosphoenol pyruvate carboxylase [54]. This feature may partly explain the observed salinity tolerance in many C_4 species.

From the low water potentials observed, the suggestion was made that Kochia plants continued to exchange water vapor, oxygen, and CO_2 with the atmosphere for most of the day. The metabolism of the plant appeared to be modified to allow for continued growth at lower water potentials. For this reasons, plants such as Kochia are well suited to hot, bright regions [9].

7.5 Autoallelopathy

Several phytotoxic compounds have been found in Kochia: caffeic acid, chlorogenic acid, ferulic acid, myricetin, quercetin, saponins, alkaloids, oxalates, and nitrates [55–57]. Although these compounds are known inhibitors, they had no effect on Kochia germination because it germinates rapidly. Inhibition of growth was dramatic once the seedlings reached 40–60 h of age. Evidence to support auto-toxicity also came from field observation which showed that second year growth had a large density but much reduced growth.

Kochia can be toxic to livestock if consumed in large quantity, and death of cattle, sheep, and horses has been reported [58]. Toxic substances identified in Kochia include saponins, alkaloids, oxalates, and nitrates [55–57].

7.6 Insect Resistance

Kochia foliage contains compound(s) with insecticidal activity, and extracts from ground Kochia shoot biomass were found to have acaricidal activity (contact and systemic toxicity) against three species of mites (Tetranychus spp.; Acari: Tetranychidae) [59]. In an early study on Kochia, reported that, it was resistant to damage by grasshoppers [60]. In 1 year, yields from sweet clover were non-existent caused by grasshopper damage; Kochia remained unaffected.

7.7 Other Characteristics

Kochia may be detrimental to human health as a pollen allergen. In a study in Thailand, Kochia pollen was the second most important weed allergen, with 14 % of 100 patients with allergic rhinitis sensitized to it [61]. In Saudi Arabia, 51 % of indigenous patients and 28 % of North American expatriates living in the area (total of 1,159 patients) were sensitized to Kochia pollen, which ranked 2nd and 7th most important allergen resulting in sensitization in the respective groups [62]. Kochia is cultivated in Japan and China where the young shoots are used as a vegetable, and the seeds are used medicinally or ground into flour [9]. Kochia is cultivated in the countryside in China and Russia for making brooms [9]. The dried branches of this plant are harvested at the ripening stage for use as a broom for open-space cleaning, for example, cleaning public avenues [38].

8 Ions Accumulation of Kochia

Kochia leaf Na at vegetative stage was higher than flowering and ripening stages [31]. All Na which is transported to shoot remain there, because plant reabsorbs less amount of Na by phloem [32]. Na loading to shoot can be controlled by Na loading in xylem [63]. Higher amount of Na and K in shoot showed that both of these anions have role for regulating osmotic potential [64]. K content of leaf was twice the Na content even in the non-saline condition. K content of Kochia is 2.6–2.9 % of dry weight [24]. Salinity treatment 1.5–42 dS m^{-1} at initial growth changed Na/K ratio from 1.86 to 0.86 [32]. It is seems that plant ability for maintaining Na/K ratio in salinity tolerance of plant [65].

Leaf had the highest Cl accumulation [31]. Results showed that Cl content of stem was not affected up to 35 dS m^{-1} salinity. Leaf can tolerate 400 mM Cl in leaf; even very sensitive plant (lemon) can tolerate 250 mM Cl in leaf [63]. Salinity tolerance of Kochia to Cl is more than sulfate [66]. Selective absorption of anions showed that plant can exclude more Na and absorb more K; that showed the higher capacity of root system to absorb K [67]. Selective absorption of K increased by raising salinity up to 21 dS m^{-1} and after that decreased. By increasing Na in irrigation water selective transport of plant for K decreased and plant absorbed more Na.

Table 3 Saline water effect on Na accumulation (Kg ha^{-1}) in the soil, and in plant at vegetative, flowering and ripening stages

Salinity (dS m^{-1})	Soil Na	Plant Na content		
		Vegetative	Flowering	Ripening
1.5	130.5	130.8	274.2	200.1
7.0	559.7	141.2	224.2	224.9
14	1095.7	108.7	215.5	333.0
21	1621.7	86.2	180.5	258.9
28	2478.7	69.4	205.8	231.7
35	2683.6	57.6	128.9	200.9
42	3214.6	78.0	135.8	238.5

Because of the raising Na content of irrigation water; plant Na/K ration increased by raising salinity [31].

Selective transportation of anions showed that root can control Na transportation and more K transported to leaf. Increasing salinity increased selective transportation and decreased Na transportation to leaf. Results showed that Na/K ratio at root is more than leaf and stem. In comparison of other halophytes like *Echinochloa frumentacea*, Kochia is a salt excluder [68]. Using saline water increased Na content of soil (Table 3). Kochia is a C_4 plant that uses NADP-ME in the C_4 photosynthetic pathway [50, 69], and displays a kochioid type of C_4 Krantz anatomy [51, 52]. A specific feature of such C_4 pathway is the requirement for sodium (Na) as a micronutrient [53]. Sodium may have a physiological role in enhancing *in vivo* activity of the C_4 enzyme phosphoenol pyruvate carboxylase [54]. This feature may partly explain the observed salinity tolerance in many C_4 species. With raising salinity despite the increasing Na accumulation in plant decreased because of decreasing shoot biomass. According to the result, it seems that plant can absorb all the Na if 3 dS m^{-1} saline water is used.

Kochia may need Na as a micronutrient [31]. Root system of this plant absorbs and transports Na to shoot selectively. Besides selective absorption, Na transport from root to shoot is selectively and all these factors help Kochia to manage Na/K ratio. Kochia can tolerate Cl accumulation in leaves (Table 4). These two strategies, selective absorb and transport, are used for maintenance of Na/K ratio in

Table 4 Saline water effect on Cl accumulation (Kg ha^{-1}) in the soil, and in plant at vegetative, flowering and ripening stages

Salinity		Plant Cl content		
(dS m^{-1})	Soil Cl	Vegetative	Flowering	Ripening
1.5	49.4	308.4	504.7	735.8
7	212.5	333.2	414.8	771.1
14	418.1	274.4	441.8	1108.4
21	623.6	231.4	335.1	757.1
28	829.1	193.7	420.8	712.2
35	1034.6	149.0	289.3	664.9
42	1240.2	137.5	295.8	544.7

Table 5 Salinity effect on Na/K at vegetative, flowering and ripening stages and selective absorption (SA) of anions

Salinity		Na/K plant		
dS m^{-1}	SA	Ripening	Flowering	Vegetative
1.5	7.85 abc	0.53 cd	0.68 bc	0.68 abc
7	9.71 a	0.67 cd	0.72 bc	0.63 bc
14	8.13 ab	0.96 ab	0.61 c	0.59 c
21	10.27 a	0.79 bc	0.80 abc	0.85 a
28	6.73 bcd	0.85 abc	0.80 abc	0.77 abc
35	4.69 d	1.02 a	0.91 ab	0.88 a
42	5.44 cd	0.93 ab	0.97 a	0.80 ab

Kochia (Table 5). Despite Kochia can maintain sodium at low level but it needs to spend a lot of energy and which in the end reduces the amount of plant biomass. The main advantage over other halophyte plants is in the feed value, because low amount of leaf Na raise feed value.

9 Water Use Efficiency and Water Productivity

One of the most important reasons for interest in Kochia is that it has low water use relations to the amount of dry matter produced when compared to other crops. Primary advantage of the C_4 photosynthetic pathway is the associated high water-use efficiency (WUE); C_4 species have higher ratios of photosynthesis to transpiration than C_3 species [54]. A study in New Mexico found that the WUE of Kochia was about three times that of alfalfa [39]. In a study in Iran, WUE in Kochia, subjected to irrigation water of varying salinity levels, ranged from 7.6 to 11.9 kg biomass mm^{-1} evapotranspiration and 2.4 to 2.9 kg seed mm^{-1}[27]. Kochia was about equal, in water use efficiency, to red root pigweed (*Amaranthus retroflexus*) and wild oats (*Avena fatua*) at 275 g of water used for each gram of forage produced [70].

Water productivity of Kochia decreased with raising salinity and water application. The highest water productivity was observed at 1.5 dS m^{-1} and 50 % water application treatment and the lowest was at 35 dS m^{-1} and 125 % water application. Salinity affects soil water potential and reduces soil available water or stomatal closure and evapo-transpiration rate reduction, leaf area and size reduction [71, 72]. Increasing salinity reduces root growth and water absorption [73]. Increasing salinity and water application decrease salinity effect on water productivity because abundant water is available for plant. Generally, deficient irrigation can be used in Kochia in the presence of salinity.

10 Possible Utilization of Kochia

10.1 Hay Production

Kochia has been used as a livestock feed during periods of forage shortages resulting from drought, in 1988 across the Canadian Prairies and USA Great Plains when the value of non-cultivated Kochia harvested as emergency forage in southern Saskatchewan was estimated at $7 million (Saskatchewan Research Council 1992). As a dry land forage crop in arid to semiarid regions, Kochia has several noteworthy characteristics including drought, salinity, and grasshopper (Orthoptera: Acrididae) tolerance, leafiness, high vegetative and seed yields, and high protein and carbohydrate content [60]. In the semiarid Canadian Prairies, forage production generally averages 4–7 t ha^{-1} annually; early spring and fall-seeded Kochia in southwestern Saskatchewan yielded between 5.4 and 10.9 t ha^{-1} on a severely saline soil [74]. Harvested during the vegetative stage, crude protein content ranges from 10 to 25 %, but decreases as the plant matures [75].

10.1.1 Forage Quality of Kochia

Digestibility of Kochia forage crude protein, digestible energy, and intake by sheep were lower than alfalfa [76]. Kochia forage has relatively high digestibility *in vitro* when harvested at the flowering stage compared with mature Kochia [24].

No difference was found in dry matter intake or dry matter digestibility when goats were fed diets of varying proportions (0–100 %) of fresh Kochia and ammoniated barley (*Hordeum vulgare* L.) straw [77]. Kochia hay can be fed at levels between 25 and 50 % of the diet without adverse effects on intake or digestibility by sheep [78]. Numerous feeding trials have generally concluded that Kochia fodder should not comprise the majority of the diet and pure Kochia stands should not be grazed by livestock [57]. In a feeding study in Saskatchewan, beef steers were fed rations with varying amounts of Kochia hay harvested from a saline flat in a field; the hay contained 2.6 % soluble oxalates and 0.5 % nitrates [79]. A later study by found that the maximum nitrate-N accumulation in Kochia forage was 0.5 g kg^{-1}, which was less than the recommended 1.1 g kg^{-1} (0.11 %) nitrate-N upper limit for livestock feed to avoid poisoning [80]. As the proportion of Kochia in the steers' diet exceeded 60 %, dry matter intake and N retention declined sharply [79]. Both urinary and fecal N excretion increased with increasing levels of Kochia in the diet, indicating possible liver and kidney damage.

Feeding trials with sheep indicated high digestible crude protein (83 %) and low total digestible nutrient value (57 %) for immature Kochia, and relatively low dry matter consumption per day; these values declined and crude fiber content increased with advanced growth stage [75]. The quality and quantity of forage production in intercropping of Kochia (*Kochia scoparia L.*) with Blue Panic Grass (*Panicum antidotale*) under irrigation with saline water was evaluated [81]. Mix of 50 % Blue Panic Grass and 50 % Kochia with an average of 1,408 g m^2 had the highest dry matter yield and then treatment 25 % Blue Panic Grass and 75 % Kochia and 75 % Blue Panic Grass and 25 % Kochia were 1,317 and 993 g m^{-2}, respectively. Due to lower growth rate of Blue Panic Grass (perennial) in the first year, a large proportion of dry matter per treatment was associated with Kochia and land equivalent ratio was less than one in all intercropping treatments. In first and second clippings, there was no significant difference between intercropping treatments in terms of crude protein, ash, NDF and ADF.

Previously reported that after being pastured on Kochia for 5 months, one cow had died and others were sick [82]. Photosensitization was evident in the sick animals as they had swollen eyelids, swollen necrotic muzzles, lacrimation, necrotic skins under white hair patches, and a necrosis of teat ends. The animals were generally lethargic and depressed. Some blindness was also noted in a few of the animals. Problems were alleviated once cattle were removed from the Kochia pasture. Although Kochia was considered a good feed, caution was recommended in its use.

Sheep grazing on Kochia pasture for 45–50 days became reluctant to graze and developed nasal swellings and nasal necrosis along with other complications [58]. In all cases, problem developed while animals were on mature Kochia. Kochia toxicity was thought to be related, in part, to high oxalate content in mature plants. Because of potential toxicity problems, a diet consisting of no more than 50 % Kochia is recommended [78].

Following various isolation experiments, and small animal feeding trials, the New Mexico researchers concluded that the toxic agent was an alkaloid. Some evidence was obtained recently that the alkaloid was spartine [83]. Previously isolated very small amounts of harmane and harmine alkaloids from Kochia [84]. Feeding trials with cattle showed that Kochia could be fed at amounts up to 40–50 % of the diet to cows without problems. Above 50 %, however, the animals' intake of feed fell off quit rapidly. The best stage of maturity to cut Kochia for hay was at late bud or early flower. This was the best compromise between yield, crud protein content, digestibility and reduced levels of nitrate and oxalate. Crimping the hay seems very important to hasten drying (e.g. use haybine type of equipment) [83].

Silage made from second growth Kochia at a height of 12 in. and from mature plants 5 ft. tall was evaluated [60]. The silage was considered satisfactory with and without the use of molasses. Intake of Kochia silage was dependent on the age of harvest. Plants harvested earlier had higher leaf: stem ratios and were much more preferred [75].

10.2 High Protein Seed Crop

Kochia produce high protein seed, which can be used in poultry feed. Fed turkey poults rations containing 15 or 30 % Kochia seed (25–33 % crude protein), with the saponins present in the seed either removed by washing with sodium hydroxide (NaOH) or inactivated by mixing the whole seed with phytosterols [85]. The control treatments, unwashed Kochia seed or seed without added phytosterols, resulted in 40 and 93 % mortality for the 15 and 30 % rations, respectively. If using Kochia in the ration, a diet containing 15 % Kochia seed treated with 1 % NaOH was recommended.

10.3 Phytoremediation

Kochia does not appear to be a suitable crop to mine salts from saline soils in an attempt to reduce salinity [86]. Research at Baildon, Saskatchewan showed that Kochia was useful in stabilizing of a particular saline site. Kochia was established on a localized saline seep in down slope position and alfalfa was planted in the upslope recharge area. After several years under normal forage management, marked soil improvement was detected in the seep. Previously noted that even though Kochia is not always a cure for saline soils, the yield potential and subsequent economic return from unproductive soils is of major interest [86]. Kochia is reported to have fairly high potassium (K), magnesium (Mg), calcium (Ca), and low chloride (Cl) contents [66, 87], tends to accumulate K and exclude sulfate relative to concentrations of these ions in the soil.

Kochia is also beneficial in phytoremediation, ranking 6th out of 10 plant species in bioaccumulation of cesium-137 from solution [88]. The species may also make easier remediation of hydrocarbon-contaminated soil, as Kochia and some native perennial grasses were the most abundant species at contaminated sites in southern Saskatchewan [89]. Furthermore, the rhizosphere of Kochia significantly enhances the microbial-mediated mineralization of herbicides such as atrazine and metolachlor, and insecticidal hexachlorocyclohexane isomers [90].

10.4 Edible Oil Crop

The oil content of Kochia seeds was between 8.4 % in the non-saline and 7.8 % under 42 dS m^{-1} salinity, and the effect of treatments on oil content was not significant. Drought stress up to 40 % of water application did not have significant effect on oil content [38]. Kochia could produce 192 kg ha^{-1} oil at 25 % of deficit irrigation and 1.5 dS m^{-1}; and 120 kg ha^{-1} at 42 dS m^{-1} and 50 % of deficit irrigation. Canola could not produce seed at 35 dS m^{-1} but Kochia produced 138 kg ha^{-1} oil in this level of salinity [91].

Analysis of Kochia's seed oil showed the presence of 14 fatty acids of which five were saturated and nine were unsaturated fatty acids (Table 6). Saturated and unsaturated fatty acid contained 12 and 84 % of seed oil content, respectively. Palmetic ($C_{16:0}$) was the dominant saturated fatty acid (8.4 %), and linoleic (50 %) and oleic (20 %) acids were the dominant unsaturated fatty acids. Kochia seeds also contained 4.7 % α-linolenic acid. Linoleic and α-linolenic acids are the two essential fatty acids that the human body needs and cannot manufacture [92]. The oil content of the halophytes of Pakistan was evaluated and reported that they did not have oleic and lenoleic acids in their oil components [93]. Kochia oil contains 4.6 %, 5- Hexadecanoic acid. Previously reported that this fatty acid can be used to control the disease carrying mosquito *Cluex quinquefaciatus* [94]. This unusual fatty acid is produced in the seed of *Kochia scoparia*. Kochia oil contains 28 % mono-unsaturated and 56 % poly-unsaturated fatty acids; therefore, Kochia seeds have the potential to be used as a source of edible oil.

Table 6 Saturated and unsaturated fatty acid fractions (%) in the oil of Kochia seeds

Fatty acid		Percent
Saturated		
Hexadecanoic acid methyl ester (palmetic)	$C_{16:0}$	8.39
Octadecanoic acid methyl ester (stearic)	$C_{18:0}$	2.74
Eicosanoic acid methyl ester (arachdic)	$C_{20:0}$	0.92
Docosanoic acid methyl ester (behenic)	$C_{22:0}$	0.06
Tetracosanoic acid methyl ester (lignoceric)	$C_{24:0}$	0.12
Total		12.23
Unsaturated		
5- Hexadecanoic acid methyl ester	$C_{16:1}$	4.59
9-Hexadecanoic acid methyl ester (palmitoleic)	$C_{16:1}$	0.14
9- Octadecanoic acid methyl ester (oleic)	$C_{18:1}$	19.69
5- Octadecanoic acid methyl ester	$C_{18:1}$	2.22
11- Eicosanoic acid methyl ester (gadoleic)	$C_{20:1}$	1.32
5, 9- Octadecanoic acid methyl ester	$C_{18:2}$	0.69
9, 12-Octadecanoic acid methyl ester (linoleic)	$C_{18:2}$	49.90
5, 9, 12- Octadecanoic acid methyl ester	$C_{18:3}$	0.63
9, 12, 15-Octadecanoic acid methyl ester (α-linolenic)	$C_{18:3}$	4.67
Total		83.85

Table 7 Lignin and other inhibitors in Kochia

Parameter	Units	Mean	St. dev.
Insoluble lignin	%	16.1	0.6
Soluble lignin	%	1.9	0.1
Hydroxymethylfurfural	mg g^{-1}	13.3	3.3
Furfural	mg g^{-1}	245.4	9.0
4-hydroxybenzoic acid	ug g^{-1}	35.2	1.0
Vanillic acid	ug g^{-1}	185.0	6.1
Syringic acid	ug g^{-1}	1017.8	27.5
4-hydroxybenzaldehyde	ug g^{-1}	89.6	3.4
Vanillic aldehyde	ug g^{-1}	73.2	13.7
Syringic aldehyde	ug g^{-1}	344.9	20.5

10.5 Potential Use of Kochia as Biofuel

Biomass-based ethanol (or bioethanol) is well-entrenched as a potential substitute for petroleum-based gasoline. One of the primary benefits of switching to this fuel is that biomass is renewable, and can potentially provide a sustainable fuel supply over the long term [95].

Many biofuels generate large benefits when compared to fossil fuels. Cellulosic materials are comprised of lignin, hemicelluloses, and cellulose and thus are sometimes called lignocellulosic materials. They have to be converted to five and six carbon sugars, before they can be fermented and converted into ethanol. Lignin which contains no sugars encloses the cellulose and hemicelluloses molecules, making them difficult to reach. Cellulose molecules consist of long chains of glucose molecules as do starch molecules, but have a different structural configuration. These structural characteristics plus the encapsulation by lignin makes cellulosic materials more difficult to hydrolyze than starchy materials. Also hemicelluloses is comprised of long chains of sugar molecules [96].

The feasibility of converting ligno-cellulosic vegetative biomass of plants into sugar, which is subsequently fermented to ethanol, opens new venues to tackle the problem of 'food or fuel' because the grain is spared for food in the process. Halophytes grow under conditions where both available water and soil are saline [97]. Therefore use of halophytes as biofuel crop is advantageous because they do not compete with conventional crops for high quality soil and water and hence do not encroach on the resources needed for food crops [98]. Kochia cellulose content was 40 % lower than Ethiopian mustard (Brassica carinata) residue, Kochia cellulose was 30 % lower than wheat straw and alfalfa, but only 15 % lower than corn stoffer. Hemicellulose content in kochia was fairly similar to that in alfalfa and corn, while kochia lignin was similar to lignin in other biomass feedstocks. Alfalfa biomass had the lowest hemicellulose content and oats the highest, with more than two fold difference between the two crops. Overall, the cell wall structure of kochia was most similar to corn stoffer.

During hydrolysis of lignocellulosic materials a wide range of compounds which are inhibitory to microorganisms are formed or released. Based on their origin the inhibitors are usually divided in three major groups: weak acids, furan derivatives, and phenolic compounds. These compounds limit efficient utilization of the hydrolysates for ethanol production by fermentation. If the inhibitors are identified and the mechanisms of inhibition elucidated, fermentation can be improved by developing specific detoxification methods, choosing an adapted microorganism, or optimizing the fermentation strategy [99]. Table 7 showed lignin and other inhibitors of Kochia. Vanillin, a major phenolic compound, has been suggested to be a stronger inhibitor of growth and bioethanol fermentation than other inhibitors because vanillin acts at low concentrations [100]. Furfural and hydroxymethylfurfural (HMF) are representative inhibitors among many inhibitive compounds derived from biomass degradation and saccharification for bioethanol fermentation. Most yeasts, including industrial strains, are susceptible to these inhibitory compounds, especially when multiple inhibitors are present [101]. *p*-Hydroxybenzoic aldehyde, a lignin-degradation product is more inhibitory than the sugar-derived products, such as furfural and 5-hydroxymethylfurfural [102].

Glucose was the main sugar of Kochia. Larger amounts of glucose are advantageous for ethanol production because glucose can (currently) be converted at higher yields to ethanol than most other sugars, especially compared to pentoses like xylose and arabinose. Xylose content of Kochia was the same as other alfalfa but arabinose was higher in Kochia.

This result suggests that Kochia can compete favorably with other conventional sources for biofuel production. It provides an option of selecting high biomass plant that contain suitable ligno-cellulosic material for conversion into ethanol and can be grown without encroaching upon arable land and fresh water.

References

1. Ashraf M (2004) Some important physiological selection criteria for salt tolerance in plants. Flora 199:361–376
2. Belligno A, Sardo V (2008) Studies on halophytes and salinity problems in Mediterranean agriculture. In: Lieth H, García Sucre M, Herzog B (eds) Mangroves and halophytes: restoration and utilization. Springer, Dordrecht, Netherland
3. Akhani H (2006) Biodiversity of halophytic and sabkha ecosystems in Iran. In: Khan MA, Boer B, Stanislavovich kust G, Barth HJ (eds) Sabkha ecosystems, West and Central Asia, vol 2. Springer, Dordrecht, Netherland
4. Flowers TJ, Colmer TD (2008) Salinity tolerance in halophytes. New Phytol 179:945–963
5. UNDP (1999) Human development report. www.undp/hdro/population.htm
6. Khan MA, Duke NC (2001) Halophytes – a resource for the future. Wetl Ecol Manag 6:455–456
7. Rogers ME, Craige AD, Munns R, Colmer TD, Nichols PGH, Malcolm CV, Barrett-lennard EG, Brown AJ, Semple WS, Evans PM, Cowley K, Hughes SJ, Snowball R, Bennett SJ, Sweeney GC, Dear BS, Ewing MA (2005) The potential for developing fodder plants for the salt-affected areas of Southern and Eastern Australia: an overview. Aust J Exp Agric 45:301–329
8. Koyro HW, Geißler N, Hussin S, Huchzermeyer B (2008) Survival at extreme locations: life strategies of halophytes – the long way from system ecology, whole plant physiology, cell biochemistry and molecular aspects back to sustainable utilization at field sites. In: Abdelly C, Öztürk M, Ashraf M, Grignon C (eds) Biosa-line agriculture and high salinity tolerance. Birkhäuser Verlag, Basel
9. Friesen IF, Beckie HJ, Warwick SI, Van Acker RC (2009) The biology of Canadian weeds. 138. *Kochia scoparia* (L.) Schrad. Can J Plant Sci 89:141–167
10. USDA (1967) Food and your weight, Bulletin no. 74. USDA, Washington, DC
11. Frankton C, Mulligan GA (1987) Weeds of Canada (No. 948). NC Press Limited, Toronto
12. Heap IM (2008) International survey of herbicide resistant weeds. [Online] Available: http://www.weedscience.org. Accessed 15 Mar 2008
13. Guttieri MI, Eberlein CV, Thill DC (1995) Diverse mutations in the acetolactate synthase gene confer chlorsulfuron resistance in kochia (*Kochia scoparia*) biotypes. Weed Sci 43:175–178
14. Stallings GP, Thill DC, Mallory-smith CA, Shafii B (1995) Pollen-mediated gene flow of sulfonylurea-resistant Kochia (*Kochia scoparia*). Weed Sci 43:95–102
15. Mulugeta D, Maxwell BD, Fay PK, Dyer WE (1994) Kochia (*Kochia sco-paria*) pollen dispersion, viability and germination. Weed Sci 42:548–552
16. Blackwell WH, Powell MJ (1981) A preliminary note on pollination in the chenopodiaceae. Ann Mo Bot Gard 68:524–526
17. Bell AR, Nalewaja JD, Schooler AB (1972) Light period, temperature, and Kochia flowering. Weed Sci 20:462–464
18. Braidek J, Fedec P, Jones D (1984) Field survey of halophytic plants of disturbed sites on the Canadian Prairies. Can J Plant Sci 64:745–751
19. Everitt JH, Alaniz MA, Lee JB (1983) Seed germination characteristics of *Kochia scoparia*. J Range Manag 36:646–648

20. Evetts IL, Burnside OC (1972) Germination and development of common milkweed and other species. Weed Sci 20:371–378
21. Sabouri S (2012) Study different aspects of germination of Kochia seed (*Ko-chia scoparia* (L.) Schard) as a new forage crops. Dissertation, Ferdowsi University of Mashhad
22. Niemegeers MA (1994) *Kochia scoparia* (L.) Schard: a potential agricultural crop. University of Saskatchewan, Saskatoon
23. Lugg DJ, Cuesta PA, Norcross GY (1983) Effect of N and P fertilization on yield and quality of Kochia grown in the greenhouse. Commun Soil Sci Plant Anal 14:859–875
24. Kernan J, Souslski K, Green D, Knipfel J, Coxworth E (1986) Kochia and other forage as energy crops. Saskatchewan Research Council R-811-1-e-86
25. Khaninejad S, Kafi M, Nabati J (2011) Evaluation the effect of nitrogen and phosphorous levels on physiological characteristics and forage yield of *Kochia scoparia* in irrigating with two saline waters. In: Proceeding of the second national plant physiology conference, Yazd
26. Salehi M, Kafi M, Kiani A (2009) Growth analysis of Kochia (*Kochia sco-paria* (L.) Schrad) irrigated with saline water in summer cropping. Pak J Bot 41:1861–1870
27. Jami Al-Ahmad M, Kafi M (2007) Kochia (*Kochia scoparia* (L.): to be or not to be. In: Kafi M, Khan MA (eds) Crop and forage production using saline waters. Daya Publishers, India
28. Nussbaum ES, Wiese AF, Crutchfield DE, Chenault EW, Lavake D (1985) The effects of temperature and rainfall on emergence and growth of eight weeds. Weed Sci 33:165–170
29. Sabouri S, Kafi M, Nezami A, Banayan M (2011) Evaluation of base, optimum and ceiling temperature for Kochia scoparia. J Agroecol 3:191–197
30. Al-Ahmadi MJ, Kafi M (2006) Salinity effects on germination properties of *Kochia scoparia*. Asian J Plant Sci 5:71–75
31. Salehi M (2010) Effects of salinity and deficit irrigation on biomass production and physiomorphological aspects of Kochia seed (*Kochia scoparia* (L.) Schard). Dissertation, Ferdowsi University of Mashhad
32. Salehi M, Kafi M (2011) Initial irrigation time with saline water on the salt tolerance and ion content of *Kochia scoparia* (L.) Schrad at seedling stages. Span J Agric Res 9:650–653
33. Bresler E (1987) Application of a conceptual model to irrigation water requirement and salt tolerance of crops. Soil Sci Soc Am J 51:788–793
34. Shalhevet J, Vinten A, Meiri A (1986) Irrigation interval as a factor in sweet corn response to salinity. Agron J 78:539–545
35. Parra MA, Cruz Romero G (1980) On the dependence of salt tolerance of beans (*Phaseolus vulgaris* L.) on soil water matric potentials. Plant Soil 56:3–16
36. Letey J, Dinar A, Knapp KC (1985) Crop-water production function model for saline irrigation waters. Soil Sci Soc Am J 49:1005–1009
37. Shani U, Dudley IM (2001) Field studies of crop response to water and salt stress. Soil Sci Soc Am J 65:1522–1528
38. Kafi M, Asadi H, Ganjeali A (2010) Possible utilization of high-salinity waters and application of low amounts of water for production of the halophyte *Kochia scoparia* as alternative fodder in saline agroecosystems. Agric Water Manag 97:139–147
39. Foster C (1980) Kochia-Poorman's alfalfa shows potential as feed. Rangel J 2:22–23
40. Sherrod IB (1971) Nutritive value of *Kochia scoparia* (L.) yield and chemical composition at three stages of maturity. Agron J 63:343–344
41. Bassil ES, Kaffka SR (2002) Response of safflower (*Carthamus tinctorius* l.) to saline soils and irrigation. I. Consumptive water use. Agric Water Manag 54:67–80
42. Bhantana P, Lazarovitch N (2010) Evapotranspiration, crop coefficient and growth of two young pomegranates (*Punica granatum* l.) varieties under salt stress. Agric Water Manag 97:715–722
43. Gul B, Ansari R, Aziz I, Khan MA (2010) Salt tolerance of *Kochia scoparia*: a new fodder crop for highly saline arid regions. Pak J Bot 42:2479–2487
44. Kafi M, Nabati J, Khaninejad S, Masomi A, Zare Mehrjerdi M (2011) Evaluation of characteristics forage in different Kochia (*Kochia scoparia*) ecotypes in tow salinity levels irrigation. Electron J Crop Prod 4:229–238
45. Soleimani MR, Kafi M, Ziaee SM, Shabahang J, Davari K (2008) Effect of limited irrigation with saline water on seed yield and seed quality of two local populations of *Kochia scoparia* (L.) Schrad. J Agric Sci Nat Resour 15:148–156
46. Ziaee S, Kafi M, Shabahang J, Khazaee H, Soleimani M (2009) Effect of plant density and harvesting time on oil and protein yield of Kochia (*Kochia sco-paria* (L.) Schrad.) under saline irrigation conditions. J Water Soil Sci 13:639–646
47. Cary JW (1971) Energy levels of water in a community of plants as influenced by soil moisture. Ecology 52:710–714
48. Phillips WM, Launchbaugh JL (1958) Preliminary studies of the root system of *Kochia scoparia* at Hays, Kansas. Weeds 6:19–23
49. Davis R, Johnson W, Wood F (1967) Weed root profiles. Agron J 59:555–556
50. Kadereit G, Borsch T, Weising K, Freitag H (2003) Phylogeny of Amaran-thaceae and Chenopodiaceae and the evolution of C_4 photosynthesis. Int J Plant Sci 164:959–986
51. Pyankov VI, Artyusheva EG, Edwards G (1999) Formation of C4 syndrome in leaves and cotyledons of *Kochia scoparia* and *Salsola collina* (Chenopodiaceae). Russ J Plant Physiol 46:452–466

52. Muhaidat R, Sage RF, Dengler NG (2007) Diversity of Kranz anatomy and biochemistry in C_4 eudicots. Am J Bot 94:362–381
53. Brownell PF, Crossland CJ (1972) The requirement of sodium as micronutrient by species having the C_4 dicarboxylic photosynthetic pathway. Plant Physiol 49:794–797
54. Collins RP, Jones MB (1986) The influence of climatic factors on the distribution of C_4 species in Europe. Plant Ecol 64:121–129
55. Cymbaluk NF, Millar JD (1986) Oxalate concentration in feeds and its metabolism by ponies. Can J Anim Sci 66:1107–1116
56. Whang WK, Hahn DR (1991) Saponins from the fructus of Kochia scoparia. Arch Pharm Res 14: 176–180
57. Rankins JDL, Smith GS (1991) Nutritional and toxicological evaluations of Kochia hay (*Kochia scoparia*) fed to lambs. J Anim Sci 69:2925–2931
58. Sprowls R (1981) Problems observed in horses, cattle and sheep grazing [Kochia scoparia, forage crop]. In: Proceedings of the annual meeting – American Association of Veterinary Laboratory Diagnosticians, Madison 397–406
59. Shi GL, Zhao IL, Liu SQ, Cao H, Clarke SR, Sun JH (2006) Acaricidal activities of extracts of *Kochia scoparia* against *Tetranychus urticea*, *Tetranchus cin-nabarinus*, and *Tetranychus viennensis* (acari:tetranychidea). J Econ Entomol 99:858–863
60. Erickson EL, Moxon AL (1947) Forage from Kochia. Agricultural Experiment Station, South Dakota State College 384
61. Pumhirum P, Towiwat P, Mahakit P (1997) Aeroallergen sensitivity of Thai patients with allergic rhinitis. Asian-Pac J Allerg Immunol 15:183–185
62. Suliaman FA, Holmes WF, Kwick S, Khouri FR, Atard R (1997) Pattern of immediate type hypersensitivity reactions in the Eastern province, Saudi Arabia. Ann Allerg Asthma Immunol 78:415–418
63. Munns R, Tester M (2008) Mechanisms of salinity tolerance. Annu Rev Plant Biol 59:651–681
64. Balnokin YV, Myasoedov NA, Shamsutdinov ZS, Shamsutdinov NZ (2005) Significant of Na and K for sustained hydration of organ tissues in ecologically distinct halophytes of the family chenopodiaceae. Russ J Plant Physiol 52:882–890
65. Shabala S, Cuin TA (2008) Potassium transport and plant salt tolerance. Physiol Plant 133:651–669
66. Bilski JJ, Foy CD (1988) Differential tolerances of weed species to aluminum, manganese, and salinity. J Plant Nutr 11:93–105
67. Pitman MG (1984) Transport across the root and shoot/root interaction. In: Staples RC, Toennissen GH (eds) Salinity tolerance in plants: strategies for crop improvement. John Wiley & Sons, New York
68. Wang S, Zhu XY (1994) Studies on the characteristics of ion absorption and distribution in *Puccinella tenuiflora*. Acta Pratacult Sin 3:39–43
69. Welkie GW, Caldwell M (1970) Leaf anatomy of species in some dicotyledon families as related to the C_3 and C_4 pathways of carbon fixation. Can J Bot 48:2135–2146
70. Baker HG (1974) The evolution of weeds. Annu Rev Ecol Syst 5:1–24
71. Katerji N, Van Hoorn JW, Hamdy A, Mastrorilli M (2003) Salinity effect on crop development and yield analysis of salt tolerance according to several classification methods. Agric Water Manag 63:37–66
72. Richard RA (1992) Increasing salinity tolerance of grain crops: is it worth-while? Plant Soil 146:89–98
73. Rengasamy P, Chittleborought D, Helyar K (2003) Root-zone constraints and plant-based solution for dryland salinity. Plant Soil 257:249–260
74. Steppuhn H, Wall K (1993) *Kochia scoparia* emergence from saline soil under various water regimes. J Range Manag 46:533–538
75. Finley IJ, Sherrod IB (1971) Nutritive value of *Kochia scoparia*: intake and digestibility of forage harvested at different maturity stages. J Dairy Sci 54:231–234
76. Moyer JR, Hironaka R (1993) Digestible energy and protein content of some annual weeds, alfalfa, bromegrass, and tame oats. Can J Plant Sci 73:1305–1308
77. Madrid J, Hernandez F, Pulgar MA, Cid JM (1996) Nutritive value of *Kochia scoparia* (L.) and ammoniated barley straw for goats. Small Rumin Res 19:213–218
78. Mir Z, Bittman S, Townley-smith I (1991) Nutritive value of Kochia (*Kochia scoparia*) hay or silage grown in a black soil zone in Northeastern Saskatchewan for sheep. Can J Anim Sci 71:107–114
79. Cohen RDH, Iwaasa AD, Mann ME, Coxworth E, Kernan JA (1989) Studies on the feeding valte of *Kochia scoparia* Schrad. hay for beef cattle. Can J Anim Sci 69:735–743
80. Steppuhn H, Green DG, Knipfel JE, Coxworth E, Kernan JA (1994) Response of *Kochia scoparia* to nitrogen fertilization on a saline soil. Can J Soil Sci 74:267–275
81. Farajian Mashhadi MA, Kafi M, Nezami A, Sharif Rohani M (2013) Qualitative and quantitative forage production in intercropping of Kochia (*Kochia scoparia* (L.) with blue panic grass (*Panicum antidotale*) under irrigation with saline water. J Agroecol 4:282–293
82. Dickie CW, Berryman J (1979) Polioencephalomalacia and photosensitization associated with *Kochia scoparia* consumption in range cattle. J Am Vet Med Assoc 175:463–465
83. Coxworth E, Green D, Kernan J (1988) Improving the agronomic and feed value of Kochia: Saskatchewan Research Council. SRC technical report no. R-814-4-b-88
84. Drost-karbowska K, Kowalewski Z, Phillipson JD (1987) Isolation of harmane and harmine from Kochia scoparia (L.). Lioydia 41:289–290

85. Coxworth E, Salmon RE (1972) Kochia seed as a component of the diet of Turkey poults: effects of different methods of saponin removal of inactivation. Can J Anim Sci 52:721–729
86. Green D, Knipfel J, Kernan J, Coxworth E (1986) Evaluation of Kochia as high yielding forage for saline soils. Paper presented at soils and crops workshop, University of Saskatchewan, Saskatoon, Canada
87. Redmann RE, Fedec P (1987) Mineral ion composition of halophytes and associated soils in Western Canada. Commun Soil Sci Plant 18:559–580
88. Lasat MM, Norvell WA, Kochian IV (1997) Potential for phytoextraction of 137cs from a contaminated soil. Plant Soil 195:99–106
89. Robson D, Knight J, Fanell R, Germida J (2004) Natural revegetation of hydrocarbon-contaminated soil in semi-arid grasslands. Can J Bot 82:22–30
90. Perkovich BA, Anderson TA, Kruger EL, Coats JR (1996) Enhanced mineralization of atrazine in *Kochia scoparia* rhizospheric soil from a pesticide-contaminated site. Pestic Sci 46:391–396
91. Steppuhn H, MT V g, Grieve CM (2005) Root-zone salinity. II. Indices for tolerance in agricultural crops. Crop Sci 45:221–232
92. Snow W (2004) Chemical and physical structure of fatty acids. http://www.supplementquality.com/news/fatty_acid_structure.html
93. Weber DJ, Ansari R, Gul B, Khan MA (2007) Potential of halophytes as source of edible oil. J Arid Environ 68:315–321
94. Whitney H, Sayanova O, Lewis MJ, Pickett J, Napier JA (2000) Isolation of two putative acyl-acl carrier protein desaturation enzymes from *Kochia scoparia*. Paper presented at 14th International symposium on plant lipids, Cardiff University, Cardiff
95. Farrell AE, Plevin RJ, Turner BT, Jones AD, O'hare M, Kammen DM (2006) Ethanol can contribute to energy and environmental goals. Science 311: 506–508
96. Dominik R, Janssen R (2007) Biofuel technology handbook. WIP Renewable Energies, Munich
97. Abideen Z, Ansari R, Khan MA (2011) Halophytes: potential source of lignocellulosic biomass for ethanol production. Biomass Bioenerg 35:1818–1822
98. Rozema J, Flowers TJ (2008) Crops for a salinized world. Science 322:1478–1480
99. Palmqvist E, Hahn-hägerdal B (2000) Fermentation of lignocellulosic hydrolysates: inhibitors and mechanisms of inhibition. Bioresour Technol 74:25–33
100. Klinke HB, Thomsen AB, Ahring BK (2004) Inhibition of ethanol-producing yeast and bacteria by degradation products produced during pre-treatment of biomass. Appl Microbiol Biotechnol 66:10–26
101. Liu ZL, Slininger PJ, Gorsich SW (2005) Enhanced biotransformation of fur-fural and hydroxymethyl-furfural by newly developed ethanologenic yeast strains. In: Davison B, Evans R, Finkelstein M, Mcmillan JD (eds) Proceedings of 26th symposium on biotechnology for fuels and chemicals. Humana Press, Totowa
102. Lee W, Lee J, Shin C, Park S, Chang H, Chang Y (1999) Ethanol production using concentrated oak wood hydrolysates and methods to detoxify. Appl Microbiol Biotechnol 78:547–559