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REVIEW ARTICLE

Crop diversification and saline water irrigation as potential strategies to save freshwater resources and reclamation of marginal soils—a review

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Abstract

Feeding 9 billion by 2050 is one of major challenges for researchers. Use of diversified crops, nonconventional water resources and rehabilitation of marginal lands are alternate options to produce more food to face climate change projections. Adaptation to climate change through climate smart agriculture practices, agroecology activities, and crop-based management packages can help transform the marginal lands from environmental burdens into productive and economic blocks. This review discusses the recent advancements on specialty group of alternate crops (oil seeds, legumes, cereals, medicinal, lignocellulose, and fruit crops) which can adapt in the marginal environments. Availability of alternate water resources (saline water, treated wastewater) for irrigation cannot be omitted. Crop diversification systems involving drought and salt-tolerant crops are likely to be the key to future agricultural and economic growth in the regions where salt-affected soils exist and/or saline aquifers are pumped for irrigation. These systems may tackle three main tasks: sustainable management of land resources and enhancement of per unit productivity; intensification of agroecological practices to increase soil fertility; and improving productivity of marginal lands for diversified climate smart crops. This review explores various aspects of marginal lands and selection of tolerant crop genotypes, crop diversification, and agroecological practices to maximize benefits.

Keywords Drought · Salt-affected soils · Saline water · Salt-tolerant crops · Forage crops · Perennials · Fruit trees · Oil seed crops · Land degradation · Marginal environment

Introduction

The global human being population will cross 9 billion by 2050, but the food production has not been significantly increased at the same rate (FAO 2011a, b). It is, therefore, imperative to enhance the food production by 44 million tons per year for the next 40 years (Tester and Langridge 2010) that equals to a 38% more than the historical trends in production. The world arable land is rapidly decreasing due to land degradation, urbanization, salinity, and drought and flooding. These entire factors contribute towards creation of challenge and causing hinders to achieve the UN development goals of sustainability. The climate change scenario is further exacerbated this challenge and make it an acute problem. The drought, as an important component of climate change scenario, should have to be tackled with all available conventional and non-conventional water resources (Setter and Waters 2003). Salinity is a big problem causing land degradation and ecosystem functioning and affecting agricultural productivity all over the world (Fig. 1; Flowers et al. 1997; Munns and Tester 2008; Hussain et al. 2015). This situation is worse in arid and semiarid countries and in coastal regions where a significant portion of the land has been affected due to salinity (Pitman and Läuchli 2002). The main reason behind the scene

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Fig. 1 **a** and **b** Water logging and salt crusts on the top soil limit crop production in arid, semi-arid regions, and salt-degraded marginal land of Umm Ul Queen, UAE

is that mostly these areas are receiving significantly less rainfall, and farmers are using more saline water in these degraded marginal lands to irrigate their crops (Malash et al. 2008). The land degradation situation is very bad in central Asian states because more than 50% land has already been converted into unfertile marginal land because of waterlogging and continuous use of low quality highly saline–sodic water for irrigation (Kijne 2005; Qadir et al. 2008).

In this scenario, a significant association between different components of crop production chain (environment, agriculture and food production, agroecology) exists that all together form the natural environment. This means that to taking care of the quality of nature and natural resources are not only a civilization requirement but also a prerequisite for the operation of agricultural production and ultimately food security. Each agricultural activity requires firstly biophysical means such as suitable land, water, and climate and secondly socio-economic conditions such as credit, infrastructure, inputs, and markets (DeClerk et al. 2012). Approximately 80% of African population live in the rural sector, and their state of food security depends directly on agricultural production or indirectly through providing for agricultural labor (Tomich et al. 1995), whereas food security is affected by a myriad of factors including poverty, incomes, and unemployment. Furthermore, environmental change will have significant impacts on household food security through extreme weather events that will have direct and indirect negative effects on household food security (IPCC 2001). The marginal lands can also contribute to food security and poverty reduction, but it depends upon several agroecosystem components such as maintain soil fertility through organic fertilizers, judicial, and safe use of non-conventional water resources (desalinated water, treated wastewater, rainwater, diseases, and pest control). Access to food is more than ever a question of interest. Recent increases in world grain prices have added to the claims that we are facing a global food crisis. Alarming population growth, natural resources degradation, unfavorable climatic conditions, and decrease in agricultural research have contributed to recent shortages in food crops and added weight to calls to increase the supply of agricultural commodities.

In this manuscript, recent publications and advances on climate resilient crops from major crops groups viz. oil seed crops (safflower, rapeseed/mustard, soybean, maize, desert gourd); food legumes (cowpea, faba bean, soybean, chickpea, sesbania, amaranth); nonlegume grain crops (barley, quinoa, amaranth, teff, sorghum, millet, triticale); medicinal crops (moringa, chia); lignocellulosic crops (perennial crops, grasses, sorghum, triticale, barley); and fruit crops (date palm, olive, phalsa, jambolan, guava Indian jujube, Indian gooseberry, karanda) have been considered. In the second part of the review with the need for pragmatic and empirical data, we focused on the agrobiodiversity perspectives of marginal lands and crop yield reduction following exposure to major abiotic constraints (drought, salinity) with the aim to improve our understanding on general topics such as crop agronomy (brief botanical description, food/nutritional value), adaptation strategies, and potential marginal areas for their cultivation. The specific objective of this review is to collect in a unique manuscript the last update on salt and drought tolerant crops and their adaptation strategies in marginal environments to provide detailed information that can contribute towards poverty alleviation, food security, and environmental sustainability in degraded areas.

Methodology

For this review article, we followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The study mainly focused on literature navigation from 1964 to 2020. The literature synthesis involved arid and semiarid regions with a main focus on studies conducted in the

West Asia and North Africa (WANA) region categorized among the "highly saline-degraded marginal lands" (Hussain et al. 2019; Rodríguez et al. 2020a, b; Lyu and Xu 2020). The articles highlighting relationship (correlations and causations) between salinity and drought impact and plant tolerance potential were selected.

A systematic literature search on salinity and drought as important growth limiting factors, and on diversification of crops and crop varieties in respect to their capacity of salinity and drought adaptation/tolerance thus suitable for cultivation in marginal environments, was done. Four databases viz. Google Scholar, Scopus, Web of Science and Centre for Agriculture and Bioscience International (CABI) were used. The selection of these data bases depends upon large articles collection and their widely availability in PRISMA systematic reviews. However, CABI database is more focused on plant biology, agriculture, and environmental science research.

We determined keywords addressing the following topics: (1) oil seed crops, (2) legume crops, (3) cereal grain crops, (4) medicinal crops, (5) lignocelluloses crops, (6) and fruit crops. We revised literature from the abovementioned data bases during 2018–2019 and used wildcards (*) to account for various word spellings. We identified 1037 articles and added 126 articles through the references section of the retrieved articles. We added 27 additional records from previous knowledge and from a recently published systematic review of the nutritional drivers of food selection (Hussain et al. 2019).

The second part of the review was focused on agrobiodiversity and on its usefulness in marginal areas targeting mainly North Africa and West Asia, farmers' perception, and impact of biodiversity on crop yield and physiological attributes, especially plant growth, biochemical, and yield traits. Contingency tests were used to evaluate the effects (positive or negative) of salinity and drought on crops for finding a relationship between crop growth and yield threshold, under these abiotic stresses.

Results

Following the identification, screening and eligibility phases, we identified 425 out of 1190 articles that fit our selection criteria. From these, 125 duplicates were deleted. Meanwhile, a total of 300 full texts were reviewed in detail and assessed for inclusion in this systematic review.

The lack of consistent keywords used in research related to morphological characteristics and physiological aspects necessitated the broad selection of keywords utilized. Naturally, a broader search resulted in many hits; several of which were irrelevant leading to the large number of articles excluded. Examples of some of the article topics considered irrelevant for this systematic review included salinity, drought, and heavy metal–related ecosystem impact on growth, yield, and quality of date fruit flesh, GIS spatial assessments of land use for date cultivation, and any discussion of biochar production from different plant parts (leaves, stem, bark, flesh, and pits), and date-waste products.

Discussion

Food security, marginal lands, and agricultural productivity

Food is the main element necessary to get nutrition to maintain growth, health, and development and is the main component for economic development (Lisa et al. 2006). In a broad sense, food security exists when "all people, at all times, have physical, social, and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences to live an active and healthy life" (FAO 2001). However, food insecurity occurs when crop production system in under stress and situation will become verse. Therefore, sufficient food is not available for everyone or it is not utilized in a proper way. In developing countries and in sub-Saharan Africa, the situation is at alarming stage because of rapid population growth, soil degradation, nonavailability of good quality irrigation water and irrigation system, and change in the climate.

The present world food grain production is not adequate to feed the huge population (FAO 2011a, b). A lot of population is suffering from food insecurity and malnutrition. Agriculture is the main way of getting food, and farmers are the main workers to cultivate the soil and produce food, oil seeds, and cash crops. In sub-Saharan Africa, nonadoption of new technologies has further lagged that of Asia. Efficient, profitable, and sustainable development of marginal lands and supporting smallholder farmers in the Africa and Asia has a great potential to contribute food security in these regions. This may be achieved by lowering the dependency on other regions and increasing self-sufficiency through breeding of salt and drought crop genotypes that have better potential to survive in marginal environment due the presence of resistant genes (Fig. 2).

Marginal environment: an untapped potential

Marginal lands are the "margins of cultivation" (Tang et al. 2010) and include the "poorest land which can be remuneratively operated under given price, cost, and other conditions" (Tang et al. 2010). To fulfill the projected demand in 2050, the food production must be increased equivalent to that of the Indian subcontinent (Phalan et al. 2014).

Different types of unproductive lands can be included in the category of marginal lands. However, nutrient-poor sandy soils, salt-degraded and poor soil properties, and lands with bas quality brackish water, unproductive soils that are not

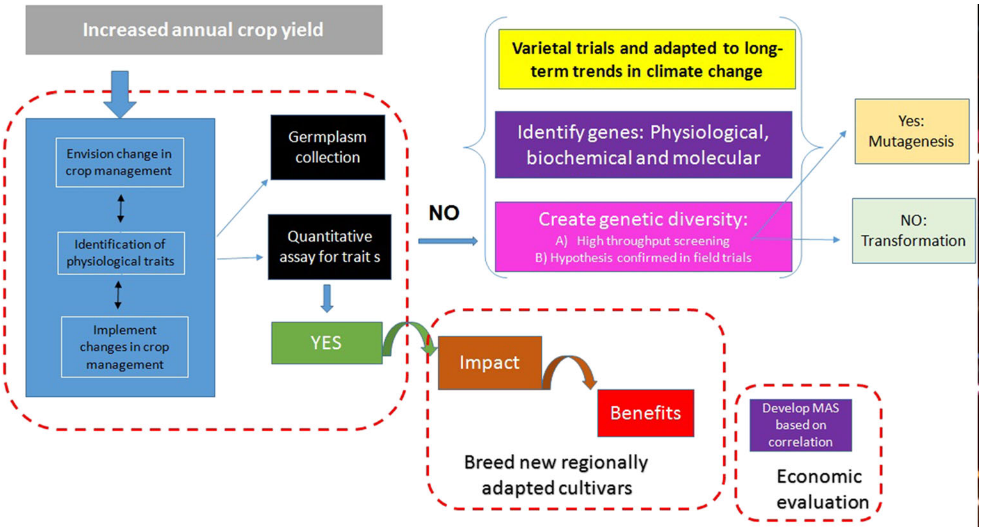

Fig. 2 Schematic flow chart showing the processes to develop new crop cultivars to meet the challenges of crop production for the next future. MAS, marker-assisted selection

suitable for any kind of vegetation are also included in this list. The typical examples of marginal lands include contaminated lands (heavy metals, salts), degraded eroded soils, and soils used for industrial and municipal wastes dumping, unproductive fallow agricultural lands (Smith et al. 2013; Tilman et al. 2006; Nixon et al. 2001; Table 1). Agricultural systems are in a state of transition to meet evolving challenges in many regions of the world, increasing global population, and degrading and depleting natural resources. This entire situation is further complicated with climate change and requires innovative solution for proper management of rapidly increasing areas of marginal lands and saline water resources. Environments can be marginal either as far as the biophysical aspects are concerned or in terms of their capacity to sustain socioeconomic activities (or of course both). An extreme example of the former is the Empty Quarter of the Arabian Peninsula, where in the absence of water, there is practically no biotic activity (Al-Dakheel et al. 2015). An example of the latter is the “slash and burn” farming systems in tropical rainforests, which yield low returns to farmers, but when undertaken through traditional farming practices ends up with different areas at different stages of a natural regeneration process. These two examples may appear marginal from one lens but sustainable from another. For example, a barren desert of sand dunes supports flora and fauna that is sustainable in the sense of being adapted to low water availability, while a low productivity farming system in the tropical rainforest mimics the local ecosystem in terms of regenerating nutrient cycles, and supporting biodiversity. Marginal areas are therefore an integral component of the overall ecosystem of humans, plants, and animals interacting with land, water, and climate variables (Al-Dakheel and Hussain 2016). The continuum of natural resources from high potential regions to marginal zones is affected by the interaction among its components, which are constantly in a state of change. Some productive areas can be reduced into marginal resources because of poor management, such as the case of salinization of irrigated lands in Central Asia, Iraq, and Pakistan (Bianchi et al. 2006). Others are examples of marginal regions being transformed into production zones through smart investments (such as tile drainage in the Egyptian delta), drip irrigation (throughout the Middle East and North Africa), and treated urban wastewater reuse (UAE, Jordan, Tunisia), all of which involved the appropriate application of science and

Table 1 Global distribution of marginal lands

Global regions	Arable land (Gha)	Forest (Gha)	Permanent meadows and pastures (Gha)	Others (Gha)
Africa	0.250	0.677	0.90	1.138
Asia	0.418	0.349	1.10	0.651
North America			0.30	
Latin America and Caribbean	0.124	0.850	0.50	0.257
Europe			0.20	
Others	0.001	0.036	0.40	0.017

Source: Rahman et al. (2014)

technology through substantial investments of public and private financial resources. These examples have expanded irrigation on large tracks of semiarid zones and desert regions in South Asia, North Africa, and Central Asia. The agroindustrial approach has focused on how to cost-effectively convert marginal environments to favorable ones through a combination of technology innovations and capital investments. Typically, better soil and water management techniques, together with innovations in technology applications, and innovative agronomic practices, have brought about this transformation. The agroecological approach by contrast explicitly incorporates natural resource management concerns in the analysis of marginal environments. It is in a better position to incorporate risks caused by climate change, unsustainable natural resource usage in assessing the sustainability of outcomes.

Food security, poverty, and marginalized farmers

Food insecurity prevails among the poor. To focus on food security, therefore, means to focus on poor people. The poverty is highest in Africa, followed by India and eastern Asia. Several thousands of resource poor farmers depend upon marginal lands and have scarce freshwater resources. The hunger is closely associated to the improvement and bringing the marginalized lands under cultivation because this is the big issue in developing world. However, farmers from these marginal lands are the main backbone of the world food security (Chappell and LaValle 2011).

Special attention to the high potential zones may have caused imbalanced resource allocation at the expense of regions with poorly endowed natural resources. The impact of these agroindustrial on marginal areas have been generally minimal—evidence points to resource poor farmers not having gained much from the green revolution. However, this sizable group of about 1.4 billion people lives and works in an underlying biophysical environment is often inherently fragile to support the economic needs of growing populations in a sustainable manner. Although they are huge in terms of number, their poverty and the small-scale nature of their activities mean that marginal farmers exert little market power. Moreover, their lack of mobilization (and the obstacles to this) means that their numbers rarely translate into political voice. The communities within which they reside are typically represented in parliament by urban dwellers and/or medium–large scale agricultural producers. Furthermore, as a group they have limited or no voice even within decentralized administrative systems. Women farmers (i.e., majority of marginal farmers in sub-Saharan Africa) may also be subject to various forms of social exclusion and political marginalization. Lack of influence in centers of power is a characteristic feature of marginal farmers and one that has led to years of policy neglect.

Role of agroecology in the crop diversification for sustainable development

The vulnerability of agroecosystems

Due to climate change cascades and geographical expansion, the monocultures have significantly increased through devotion of single crop to a piece of land and cultivation of the same crop over year-to-years. In this regard, rice, wheat, maize, and potatoes roughly accounted for 60% of the food grain source while animals provide 90% of all protein source (Vigouroux 2011). During the twentieth century, 60–70% of the total land area in USA was devoted to bean (2–3 varieties), area under potato was 72% with 3–4 varieties, and 2–3 varieties of cotton were planted. Due to increasing demand for food and fuel and climate change crises, the role played by agroecological practices and services provided by them (ecological and socioeconomic) are well recognized (Altieri 2004; De Schutter 2010). Several researchers documented that modern agriculture can be vulnerable to climate change (human or natural factor) and can led to drastic reduction in crop yield, globally, and in marginal environment, particularly.

Due to climatic perturbations, drought has drastically affected 26 states of USA causing significant reduction in crop yield on an area of 55% (1 billion hectares) of the total area. The severe crop losses due to destruction of heavy monsoon rains in 2011 flood in Pakistan caused a significant reduction of planted crops, trees, and ultimately destroying 2.4 million hectares and mortality to > 450,000 livestock that resulted in huge economic losses (2.9 billion dollars) (IPCC 2014).

Various agricultural practices such as adaptation of monoculture of biofuel crops are responsible for severe insect-pests outbreak because change in agrobiodiversity can lead to elimination of natural enemies of insects/pests. The monoculture ecosystem developed in the different states of USA such as biofuel crops has significant impact on landscape diversity that reduced (24%) biocontrol service (due to decrease in natural enemies supply to soybean field. According to reports of Landis et al. (2008), soybean production was decreased in the respective states, and producers had suffered an estimated cost of $58 million per year.

The ecological role of biodiversity in agroecosystems

In agroecosystem, the species diversity plays an important role to make different species less resilient against various degree and types of environmental shocks. Protecting the species against environmental fluctuations enhancing the capacity of different component of ecosystem (support to more than one species/component, in case one species will fail) might act as buffer against ecosystem failure (Cabell and Oelofse 2012).

Enhancing agrobiodiversity to reduce vulnerability

Different agroecological practices might help to maintain a healthy ecosystem which in turn will enhance the base of plant protection, health, productivity, yield stability, and soil health, in this regard, diversification at either or both species and genetic level. This include examples of polyculture, variety mixtures at different levels (landscape or field), e.g., agroforestry, integrated crop-livestock interaction, hedgerows, and corridors. The farmers might see these options suitable for best implementation of a successful strategy for a sustainable agroecosystem.

Adaptation of diversifying cropping systems may help, in marginal environment, to reduce the incidence of insect, pest, and diseases attack that will lead to low crop damage and higher yield (Altieri 2004). In a study conducted by Zhu et al. (2000), in China, evidenced that the farmers who planted four different varieties of rice (> 3000 ha), there were 44% less blast incidence, and 89% higher yield than other famers field where single variety of rice was cultivated. The Napier grass and leguminous silver leaf (Desmodium) planted between rows of maize demonstrated an excellent repelling crops for borers and ticks and to control *Striga* (a parasitic weed) as compared with maize monoculture. Furthermore, leguminous silver leaf can increase N-fixation soil fertility and crop yield (15–20%) (Khan et al. 2010). Biodiversity plays a positive role in stability of agroecosystem, and it will be vital under future climate change scenarios (Altieri 2004). Diversity in agroecosystem will also help to buffer beside high temperature, drought episodes, and rainfall. It may also affect the crop growth yield due to differential responses from different crop plants against the environmental perturbations (Altieri and Koohafkan 2013).

Crop diversification for marginal environment

Crop diversification represents an option for marginal lands by providing economic benefits to farmers and helping at the same time the environment conservation through the improvement of soil physical properties. Different drought-, salt-, and heavy metal–tolerant crops have been screened, selected, and developed at various agriculture research centers around the world for promoting the rehabilitation of marginal lands. These crops include abiotic stress tolerant genotypes of maize, safflower, quiona, pearl millet, sorghum, barley, perennial grasses, mustard, Sesbania, and triticale. These crops showed significant salt tolerance potential and yield stability under low to high salinity that indicates their adaptation to marginal environment (Table 2). These salt and drought crops have less water requirement but wider uses as food, feed, and industrial. These properties make them promising candidate for the diversification of production systems enhancing their economic value (Al-Dakheel et al. 2015; Hussain et al. 2015; Al-Dakheel and Hussain 2016). Meanwhile developing new crop genotypes that can produce higher yield with fewer inputs or that can increase yield stability and sustainable management of all the components of production system in marginal lands are of paramount importance (Fig. 3). These crop varieties should be highly tolerant to drought, salinity, high temperature, and strongly resistant to insects, pest, and pathogens (Cooper et al. 2014). Crop diversification might occur at field and landscape scale and should include several forms of innovative practices such as agroforestry, integrated crop–livestock interaction, legume-cereal intercropping, relay cropping, perennial forage crops, etc. This indicates a variety of option that farmers can adapt to cope with climate change scenario and to combat yield loss due to continuous monocropping.

Nowadays agriculture production systems in the marginal lands need to adapt to the new climate and associated factors. Adaptation is an important stage that will help to cope with climate change severity and its impact on crop production. However, during the previous experimental work and projects conducted in West Asia and North Africa, it was observed that different types of adaptation strategies should have used. In this way, modifying different agronomic practices like changing sowing dates, introducing new stress tolerant crop genotypes, improving irrigation practices, and using non-traditional water resources will help to maintain a sustainable agroecosystem (Hussain and Al-Dakheel 2015). However, several attributes like agroecosystem diversification, integrated crop–livestock interaction, soil organic amendments, and water management will lead to enhance the general characteristics of agrobiodiversity with durable benefits.

Oil seed crops

Safflower

Safflower is an important oil seed crop mainly cultivated for highly nutritive oil (32–40%) has great genotypic and phenotypic plasticity in wide range of environments, as winter and summer crops. The seeds of different safflower varieties are enriched with vitamins (thiamine and β-carotene), essential nutrient elements, bioactive compounds, oil contents, 35-50%, and α, β, and γ tocopherols (Camas et al. 2007; Velasco et al. 2005; Khalid et al. 2017). Safflower seed oil possesses linoleic acid and tocopherol which are important polyunsaturated fatty acids (Han et al. 2009). These molecules showed several pharmacological and health perspectives. Khalid et al. (2017) showed several therapeutic properties of safflower seed oil such as atherosclerosis, skin disorders, bone-problems, and menopause.

Table 2 Yield potential of some grain, forage, vegetable, and fiber crops as a function of average root zone salinity. Based on salt tolerance data of different crops and percentage yield reduction as per unit increasing the root zone salinity (dS m^{-1}). (Source: Maas and Grattan 1999)

Crops		Average root zone salinity (dS m^{-1}) at specified yield potential		
Common name	Botanical name	50%	80%	100%
Triticale (grain)	× *Triticosecale* Wittm. ex A. Camus.	26	14	6
Kallar grassb	*Leptochloa fusca* (L.) Kunth	22	14	9
Durum wheat	*Triticum durum* Desf.	19	11	6
Tall wheat grass	*Agropyron elongatum* (Hort) Beauv.	19	11	8
Barley	*Hordeum vulgare* L.	18	12	8
Cotton	*Gossypium hirsutum* L.	17	12	8
Rye	*Secale cereale* L.	16	13	11
Sugar beet	*Beta vulgaris* L.	16	10	7
Bermuda grass	*Cynodon dactylon* L.	15	10	7
Sudan grass	*Sorghum sudanese (*Piper) Stapf	14	8	3
Sesbania	*Sesbania bispinosa* (Jacq.) W. Wight	13	9	6
Wheat	*Triticum aestivum* L.	13	9	6
Purslane	*Portulaca oleracea* L.	11	8	6
Sorghum	*Sorghum bicolor* (L.) Moench	10	8	7
Alfalfa	*Medicago sativa* L.	9	5	2
Spinach	*Spinacia oleracea* L.	9	5	2
Broccoli	*Brassica oleracea* L. (Botrytis Group)	8	5	3
Egg plant	*Solanum melongena* L.	8	4	1
Rice	*Oryza sativa* L.	7	5	3
Potato	*Solanum tuberosum* L.	7	4	2
Maize	*Zea mays* L.	6	3	2

This data serve only as a guideline to relative tolerance among crops. Absolute tolerance varies and depends on climate, soil conditions, and cultural practices. Yield potential calculated from Malik et al. (1986).

Safflower can be cultivated in saline and marginal arid lands and is more successful than other oil seed crops (Kaya 2009a, b; Hussain et al., 2016). It salt tolerant and therefore is a promising oilseed crop for arid climate (Kar et al. 2007a, b;

Fig. 3 Crop production system management components for sustainable development of nutrient poor marginal sandy desert soils; **a** Soil preparation and installation of irrigation pipes with drippers, **b** spreading of agrel sheet after seed sowing to protect the seed from birds eating, **c** profound germination and seedling growth of different crops in the field, **d** using appropriate net technology to protect the mature crop from birds attack

Hussain and Al-Dakheel 2018). Safflower can have great ability to withstand drought stress as it has very less water requirement compared with other oilseed crops. However, drought stress at reproductive phase can significantly reduce the seed yield of safflower (Table 3). For instance, drought stress at flowering and grain filling can reduce the yield by 35–50% (Istanbulluoglu 2009) and 50–62%, respectively (Istanbulluoglu et al. 2009). However, heavy irrigation rate reduced the yield by 7 and 15% in winter and summer planted safflower at early growth and flower initiation stages, respectively. Movahhedy-Dehnavy et al. (2009) reported that drought stress decreased the seed yield but also reduced the seed concentration as 12 and 49% decrease in oil concentration. However, drought stress at grain filling did not influence the oil concentration; rather, a small increase in oil concentration was observed when drought was imposed during grain filling stage (Table 5). Safflower genotypes and soil type also influence the crop performance under drought stressed condition. Santos et al. (2017) tested four safflower genotypes in sand and clay soil and found that IAPAR and IMA-4409 genotypes were relatively drought tolerant than other tested genotypes. Singh et al. (2016) demonstrated that safflower plants receiving 1–4 times less water produced 45.9, 33.6, 22.9, and 12.3% less yield than control.

In salinity tolerance evaluation trials with < 265 safflower genotypes, Fraj et al. (2013a, b, c) reported that 52 genotypes had shown salinity tolerance potential in pot culture study and were further selected for field trials. In the field trial, Fraj et al. (2013a, b, c) showed salinity tolerance potential of several hundred genotypes and screened out 20 most promising ones that were higher yielder at medium and high salinity. Safflower can be grown on marginal soils as recently Hussain and Al-Dakheel (2018) identified two salt tolerant safflower cultivars (PI248836 and PI167390) which are salt tolerant and high yield producer under salt stress. Yeilaghi et al. (2012) evaluated 64 safflower genotypes and found great variation (7.73–55.9%) among the tested genotypes for seed yield under salt stress (12 dS m^{-1}). The extent of yield reduction was low in salt tolerant genotypes (7.7–28%), while the decrease was > 40% in salt sensitive genotypes. Furthermore, genotype Darab1 produced the maximum oil yield of 1.2 and 0.85 t ha^{-1} under normal and saline conditions respectively (Table 5). Moreover, due to its ability to withstand suboptimal climate and soil condition, its cultivation has expanded on marginal land (Hussain et al. 2015). Safflower is drought tolerant crop (Lovelli et al. 2007) with a deep root system which can extract water from a depth of 1.6 m (Hojati et al. 2011; Singh et al. 2016) extend up to 1.6 m thus has the ability to grow well on and dry and marginal soils. Moreover, cultivation of drought tolerant safflower cultivar and irrigation management can improve the safflower productivity on water deficit environment and marginal land (Singh et al. 2016). Influence of salinity and drought stresses on safflower is in Tables 3 and 4.

Safflower can be a prospective crop for edible oil purposes under climate change scenario on marginal land as it has less

Table 3 Influence of salinity on grain yield of safflower

Genotypes	Salt stress	Decrease (-)/increase (+) over control		References
	7 dS m^{-1}	Seed yield	− 25.7	Hussain and Al-Dakheel (2018)
	14 dS m^{-1}	Seed yield	− 45.7	Hussain and Al-Dakheel (2018)
GILA	4.8 dS m^{-1}	Seed yield	+ 20	Francois and Bernstein 1964
GILA	8.3 dS m^{-1}	Seed yield	− 12	Francois and Bernstein 1964
GILA	12 dS m^{-1}	Seed yield	− 48	Francois and Bernstein 1964
	10 dS m^{-1}	Seed yield	− 50	Ayres and Westcott (1976)
	15 dS m^{-1}	Seed yield	− 70	Fraj et al., 2013
	7.13 ds m^{-1}	Seed yield	− 2.8	Bassil and Kaffka (2002)
	3 gl^{-1}	Seed yield	− 16.7	Aymen et al. 2012
	6 gl^{-1}	Seed yield	− 19.4	Aymen et al. 2012
	9 gl^{-1}	Seed yield	− 27.8	Aymen et al. 2012
	12 gl^{-1}	Seed yield	− 47.2	Aymen et al. 2012
PI-250190	12 ds m^{-1}	Oil yield	− 12.0	Yeilaghi et al. 2012
Hamedan 17	12 ds m^{-1}	Oil yield	− 8.53	Yeilaghi et al. 2012
Hamedan 21	12 ds m^{-1}	Oil yield	− 7.73	Yeilaghi et al. 2012
C$_{444}$	12 ds m^{-1}	Oil yield	− 55.9	Yeilaghi et al. 2012
Zargha	12 ds m^{-1}	Oil yield	− 54.0	Yeilaghi et al. 2012
Dincer	12 ds m^{-1}	Oil yield	− 52.0	Yeilaghi et al. 2012

Table 4 Influence of drought on seed yield of safflower

Safflower genotypes	Drought imposition	Decrease (-)/increase (+) in yield over control		Crop season	References
Dincer	One irrigation (vegetative stage)	Seed yield	− 25.9	Winter	Istanbulluoglu et al. 2009
Dincer	One irrigation (flowering)	Seed yield	− 34.1		Istanbulluoglu et al. 2009
Dincer	One irrigation (grain filling)	Seed yield	− 40.0		Istanbulluoglu et al. 2009
Dincer	No irrigation	Seed yield	− 48.1		Istanbulluoglu et al. 2009
Dincer	One irrigation (vegetative stage)	Seed yield	− 23.5	Spring	Istanbulluoglu et al. 2009
Dincer	One irrigation (flowering)	Seed yield	− 36.6		Istanbulluoglu et al. 2009
Dincer	One irrigation (yield formation)	Seed yield	− 46.3		Istanbulluoglu et al. 2009
Dincer	No irrigation	Seed yield	− 65.0		Istanbulluoglu et al. 2009
Zarghan 279	Drought stress at vegetative stage	Seed yield	− 15.9	winter	Movahhedy-Dehnavy et al. 2009
Varamin 295	Drought stress at vegetative stage	Seed yield	− 32.2		Movahhedy-Dehnavy et al. 2009
L.R.V.5151	Drought stress at vegetative stage	Seed yield	− 12.7		Movahhedy-Dehnavy et al. 2009
Zarghan 279	Drought stress at flowering	Seed yield	− 61.1		Movahhedy-Dehnavy et al. 2009
L.R.V.5151	Drought stress at flowering		− 55.9		Movahhedy-Dehnavy et al. 2009
Varamin 295	Drought stress at flowering	Seed yield	− 63.5		Movahhedy-Dehnavy et al. 2009
Zarghan 279	Drought stress at grain filling	Seed yield	− 19.8		Movahhedy-Dehnavy et al. 2009
L.R.V.5151	Drought stress at grain filling	Seed yield	+ 2.93		Movahhedy-Dehnavy et al. 2009
Varamin 295	Drought stress at grain filling	Seed yield	− 9.33		Movahhedy-Dehnavy et al. 2009
Dincer	Two Irrigations (early and late vegetative stage)	Seed yield	− 44.3		Istanbulluoglu 2009
Dincer	Two Irrigations (early vegetative and flowering stage)	Seed yield	− 52.3		Istanbulluoglu 2009
Dincer	Two Irrigations (late vegetative and flowering stage)	Seed yield	− 50.5		Istanbulluoglu 2009
Dincer	Two Irrigations (early vegetative and grain filling stage)	Seed yield	− 32.2		Istanbulluoglu 2009
Dincer	Two Irrigations (late vegetative and grain filling stage)	Seed yield	− 34.1		Istanbulluoglu 2009
Dincer	Two Irrigations (flowering and grain filling stage)	Seed yield	− 38.9		Istanbulluoglu 2009
Dincer	One Irrigation (early vegetative stage)	Seed yield	− 47.4		Istanbulluoglu 2009
Dincer	One Irrigation (late vegetative stage)	Seed yield	− 39.9		Istanbulluoglu 2009
Dincer	One Irrigation (flowering)	Seed yield	− 51.9		Istanbulluoglu 2009
Dincer	One Irrigation (grain filling stage)	Seed yield	− 62.1		Istanbulluoglu 2009
Dincer	Rainfed	Seed yield	− 76.2		Istanbulluoglu 2009
	287 mm less irrigation than control	Seed yield	− 45.9	spring	Singh et al. 2016
	237 mm less irrigation than control	Seed yield	− 33.6		Singh et al. 2016
	162 mm less irrigation than control	Seed yield	− 22.9		Singh et al. 2016
	84.5 mm less irrigation than control	Seed yield	− 12.3		Singh et al. 2016
Zarghan 279	Drought stress at vegetative stage	Oil yield	− 49.2	winter	Movahhedy-Dehnavy et al. 2009
Varamin 295	Drought stress at vegetative stage	Oil yield	− 12.2		Movahhedy-Dehnavy et al. 2009
L.R.V.5151	Drought stress at vegetative stage	Oil yield	+ 14.4		Movahhedy-Dehnavy et al. 2009
Zarghan 279	Drought stress at flowering	Oil yield	− 33.7		Movahhedy-Dehnavy et al. 2009
L.R.V.5151	Drought stress at flowering	Oil yield	− 48.5		Movahhedy-Dehnavy et al. 2009
Varamin 295	Drought stress at flowering	Oil yield	− 20.0		Movahhedy-Dehnavy et al. 2009
Zarghan 279	Drought stress at grain filling	Oil yield	− 6.21		Movahhedy-Dehnavy et al. 2009
L.R.V.5151	Drought stress at grain filling	Oil yield	+ 6.40		Movahhedy-Dehnavy et al. 2009
Varamin 295	Drought stress at grain filling	Oil yield	+ 6.56		Movahhedy-Dehnavy et al. 2009

water requirement and can tolerate moderate salinity and drought to some extent (Velasco et al. 2005; Hussain and Al-Dakheel 2018; Han et al. 2009; Istanbulluoglu et al. 2009; Santos et al., 2017; Fraj et al. 2013a, b, c; Yeilaghi et al. 2012). However, there is need to optimize agronomic practices for safflower production for adaptation and to improve its performance on marginal soils. Moreover, water productivity (crop per drop) and irrigation management (using drip irrigation) can help to reduce the yield losses caused by terminal drought.

Rapeseed/mustard

The seeds of mustard (*Brassica juncea* L.) crop are a good source of edible oil while tender leaves can be used for cooking the food. Rao et al. (2013b) conducted a field experiment on selected genotypes (from a global collection of 100 accessions) and reported that yield of 5 genotypes were higher than rest of the genotypes. Seed yield was highest (3.04 t ha^{-1}) in genotype ATC 93142 followed by followed by genotypes ATC 93358 (2.90 t ha^{-1}) and ATC 93337 (2.89 t ha^{-1}), respectively. In another study, Oplinger et al. (1991) demonstrated that mustard yield varied between 900 and 1200 kg ha^{-1} while it was yielded 2.5–3.0 t ha^{-1} under favorable growing conditions. Chauhan et al. (2007) screened the 14 genotypes of Indian mustard (*Brassica juncea* L.) across two locations under semiarid and irrigated conditions. They reported that yield of mustard ranged from 0.85 to 1.69 and 1.02 to 2.78 under semiarid and irrigated conditions. Among the tested genotypes, PSR-20, PRO-97024, JMMWR-941, IS-1787, PCR-7, RC-1446, and RH-819 produced more yield with under moisture stress and had relatively low drought susceptibility index. The genotypes with low drought susceptibility index for seed yield can be used in breeding programs for development of drought tolerant mustard genotypes. Moreover, mustard is most tolerant among brassica species as *B. juncea* showed least reduction in morphological traits with higher osmolyte accumulation and better K+/Na+ ratio (Kumar et al. 2009). The saline water (EC 7.48 dS m^{-1}) irrigation to mustard brassica reduced the crop yield by 12.0%, while application of canal water and saline water alternatively and as mixed irrigation reduced the yield by 4.97 and 8.0% respectively. The ability of mustard to withstand drought and salt stress with least reduction in yield compared with other crops of brassica family make it suitable candidate crop to be grown in marginal growth environment.

Soybean

Soybean (*Glycine max* (L.) Merr.) is a high valued legume crop rich in protein (40–42%) and oil contents (18–22%) (Robert 1986). According to a report of FAO (Food and Agriculture Organization) (2003), it is a major source of valuable human protein. The area and production of soybean has increased substantially since 1961–2007 with an annual growth of 4.6% (Masuda and Goldsmith (2009). Soybean is cultivated in several countries; USA is a major producer and is followed by Brazil, Argentina, China, and India (Rodríguez-Navarro et al. 2011). It can be grown on a range of soils, therefore, can be used as potential crop to improve crop diversification on marginal lands. It is moderately salt tolerant (threshold 5 dS m^{-1}), and a decline in yield was observed in soil having salinity > 5 dS m^{-1} (Ashraf 1994). Miransari and Smith (2007) reported a decline of 5.3 and 29.7% in soybean yield at 640 and 1280 kg/ha NaCl respectively (Table 5). Chen et al. (2018) reviewed the development of research on salt tolerance of soybean and reported many germplasm accessions with high salinity tolerance and genes/QTL responsible for salt tolerance in soybean, which can be used to develop salt-resistant soybean genotypes.

Soybean is, however, sensitive to drought stress at critical growth stages especially reproductive stage (Table 6). However, deep tillage before soybean cultivation in rainfed condition can reduce the yield reduction due to water stress. Moreover, soybean can improve the crop diversification on marginal lands by using it in crop rotation with cereals or nonleguminous crops, intercropping which will help in improving the soil characteristics through enhanced uptake, breaking of disease and pest cycle. Nevertheless, there is need to introduce the tolerant soybean genotypes with better agronomic practices in areas with poor soil or harsh environment to use it as potential candidate crop on marginal lands.

Maize

Maize (*Zea mays* L.) is native to Central America but can be successfully cultivated in Canada, Caribbean, America (Central, North and South), Russia, Andean mountains, Chile and Argentina (Ecoport 2010). Maize is an important crop that can be used as energy feed for ruminant livestock. In the cold environments, it is necessary to ensile the crops for year around livestock consumption (Brewbaker 2003). However, in arid, semi-arid and tropical regions, the harvest of maize at different times is always helpful to maintain green forage supply to the ruminants. In some regions, farmers also practice the supply of completely maize plant to the ruminants that is a source of nutritive green fodder year around. In water scare regions of West Asia and North Africa, maize crop is an alternate source of fodder for livestock for smallholder farmers (Potter 2016). Maize is a high energy producer that overcomes several other fodder crops from tropical and subtropical regions and is 40% below in digestibility (Brewbaker 2003). Moreover, maize is not a labor-intensive crop because it should be harvested once after 3 months compared with other forage crops that must be harvested almost monthly (Methu et al., 2006).

Desert gourd

Desert gourd (*Citrullus colocynthis* (L.) Schrad.) is a xerophytic perennial creeper native to the Mediterranean basin, the Middle East, and South Asia. This is known for its high seed oil content (Bande et al. 2012). The plant often grows as wild in sandy soils covering large areas and surviving under hyperarid Arabian desert conditions with less than 50-mm annual precipitation. The plant can grow in coastal habitat with brackish water (Qasim et al. 2011). The desert gourd can be chosen as a nonfood biodiesel feedstock crop and the possibility for its cultivation in both arid and biophysically marginal arid lands because it occurs naturally in such habitats (Menon et al. 2016). When blended with petroleum, biodiesel from the desert gourd is known to exhibit performance parameters like that of Jatropha (*Jatropha curcas* L.)—another nonfood biodiesel crop (Mathur et al. 2012). The blends also have lower smoke opacity. The natural distribution of desert gourd suggests that compared with Jatropha, it could be more suitable for growing on lands generally inhospitable to produce crops of any kind or otherwise yield a profit. In a study conducted in sandy desert, Menon et al. (2016) evaluated seed yield of different accessions of desert gourd. The seed yield ranged from 0.47 to 14.95 t ha^{-1}; the highest seed yield was harvested in KMK 1 (14.95 t ha^{-1}) followed by RMS 227 (12.37 t ha^{-1}) and RMS 244 (11.63 t ha^{-1}). However, the oil yield varied between 0.07 and 3.44 t ha^{-1}, and that was the highest in genotype RMS 228 (3.44 t ha^{-1}), followed by RMS 244 (2.28 t ha^{-1}). Interestingly, oil from desert gourd reportedly has lower viscosity (Pal et al. 2010), which could be of great advantage in terms of its potential as a biodiesel feedstock. Root and callus extracts of desert gourd have antimicrobial (Gurudeeban et al. 2010), antiinflammatory (Rajamanickam et al. 2010), antidiabetic (Gurudeeban and Ramanathan 2010), and antioxidant (Gurudeeban et al. 2010) properties.

Legume crops

Cowpea

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important protein crop that possess a well-developed root system. This is annual plant and can grow, develop, and reproduce in the warmer climates. Some species are erect, and others are climbers. Both leaves and seeds are highly nutritive while seeds are mostly cooked food. Several farmers used the plant as a forage for livestock in Asia and North Africa (Modi and Mabhaudhi 2013). Cowpea is a big source of vegetal protein and is a balance food for poor population in several countries (El-Jasser 2011). Cowpea can be grown as intercrop with many cereal crops like sorghum, maize, and millet in South Asia and North Africa region (Cook et al. 2005a, b). Madamba et al. (2006a, b) reported that through proper soil management and agronomic practices, obtained 0.5 t ha^{-1} fodder yield. Several varieties of cowpea that has dual purpose usage can provide both grain and fodder especially in Africa (Tarawali et al. 1997a, b). The dual purpose nature of cowpea makes it an ideal candidate crop for food security in North Africa, especially under climate change scenario. Mullen et al. (2003a, b) reported the global grain yield of cowpea ranged between 1.5 and 2 t ha^{-1}. However, in another study, Rao et al. (2013b) grain yield higher than 2 t ha^{-1}was recorded. Cowpea can be grown on marginal land as it can grow successfully on salt affected and water deficit soil condition. The salt and drought tolerant genotypes can produce significant yield on saline areas. Taffouo et al. (2009) conducted a study on 18 cowpea genotypes and demonstrated that yield reduction was less (9–24%) in salt-tolerant genotypes Melakh(9.3%),Tsacre (21.9%), and Garoua GG(24%), while the extent of decline was > 50% in salt-sensitive genotypes, i.e., IT97K-573-1-1 (60.3%), IT04K-227-2 (56.6%), Mouride (56.5%), and Mouola PG (53.2%) (Tables 5 and 6). Likewise, cowpea genotypes exhibit great genetic diversity under drought stress. Ishiyaku and Aliyu 2013 screened 22 cowpea genotypes for drought tolerance indices. They demonstrated that genotype IT93K-452-1 and IT98K-412-13 with drought resistance index (DRI) were drought tolerant. Recently, Belko et al. (2014) tested 30 short and medium duration cowpea cultivars for their DRI and geometric mean productivity (GMP). They found that among short duration genotypes IT85F-3139 (1.6 t ha^{-1}), IT93K-693-2 (1.48), IT97K-499-39(1.31), KVx-61-1(1.37), Mouride (1.36) produced maximum grain yield under drought stress and normal condition and exhibited the higher DRI and GMP. Likewise, for medium duration cowpea genotypes, KVx-421-25(1.80), KVx-403 (1.72), IT93K-503-1 (1.62), IT97K-207-15 (1.59), and IT96D-610 (1.57) produced maximum grain yield under terminal drought stress and possess higher DRI and GMP (Table 6). However, lowest grain yield was recorded in IT93K-93-10 and IT95M-303 (0.53 t ha^{-1}) among short duration genotypes, while IT95M-303 (0.63) produced fewer yield among medium duration cultivars under drought stress. The medium duration cowpea cultivar exhibited higher grain yield than short duration genotypes, and the extent of decline was 60–80% in drought sensitive genotypes while it was 40–50% in drought tolerant genotypes under terminal drought stress (Belko et al. 2014).

Cowpea can help to improve crop diversification on marginal lands reducing soil erosion, improving the microbial activity and nitrogen availability in soil. Moreover, abiotic stress tolerant seed and fodder cowpea cultivars can help in food security through sustainable grain and biomass production for humans and animals respectively. Moreover, cultivation of cowpea can break the cycle of disease and other pests and thus facilitate the cultivation of other field crops.

Faba bean

Faba bean (*Vicia faba* L.) is rich source of amino acids, proteins, and grown for its food and feed value. It offers ecosystem services through enhanced N fixation and cropping system diversification (Jensen et al. 2010). It can be cultivated on fertile soils but can also be grown on low fertile soils with less water. Drought is a major problem in most of the dry regions, but autumn sown crop is more resistant than spring sown. This might be due to deep root system of autumn sown crop. Moreover, it uses less water than cereals, and therefore, the carryover moisture can enhance the N uptake, growth, and grain yield of succeeding nonleguminous crop in dry land (Papastylianou et al. 1981) and semiarid conditions (Miller et al. 2002). Faba bean can tolerate moderate drought (French 1998). Faba bean survived 8 weeks after drought stress; however, there was a decline in growth, which affects the grain yield (French 1998). Limited water supply can produce comparable grain yield in faba bean (Theib et al. 2005). Al-Suhaibani (2009) found that drought stress limits the yield of faba bean. However, severe yield reduction was noticed at water level below 4000 m^3 ha^{-1} (Table 5). Faba bean can also grow on moderately saline soils. However, salt stress exceeding from 6.5 dS m^{-1} may cause a significant yield reduction (Katerji et al. 2011). Yield reduction in different legumes under salinity and drought stresses is given Tables 5 and 6.

Faba bean can improve crop diversification on waterlogged soils. For instance, Solaiman et al. (2007) demonstrated that faba bean has the greatest ability to tolerate waterlogging stress than other grain legumes. Moreover, faba bean can successfully grow in semiarid areas with low-cost production and negative impact on environment (De Giorgio and Fornaro 2004). Faba bean cultivation as crop rotation and intercropping with other crops help in improving the diversity, nutrient availability and disease and pest control (Hauggaard-Nielsen et al. 2008). There is need to develop drought tolerant faba bean cultivar as it has the potential to grow as alternate crop on low-input soils.

Chickpea

Chickpea (*Cicer arietinum* L.) is the third most cultivated legume with high nutritious value for human consumption. Almost 72% of world production is contributed by South Asia alone (FAOSTAT, 2014). It is mostly grown in dry land areas. In south Asia, it is mostly cultivated on low fertile sandy soil. It has very less input and water requirement, therefore, can be grown successfully on soils/climate where most of the commercial crops fail. It is being cultivated on many parts of the world on saline soils (Flowers et al. 2010). Improved chickpea genotypes can help in crop diversification on poor soils. Vadez et al. (2007) screened 263 chickpea accession for salinity tolerance (Table 5; 1.9 L of 80 mM NaCl per 7.5-kg Vertisol). They reported 6-fold variation in the tested germplasm, with some of the accessions produced up to 20% higher yield than previously released salt tolerant cultivar. The tolerant genotypes could maintain higher number of filled pods under salinity stress. Among the tested genotypes *desi* type was more tolerant than *kabuli* accessions. Chickpea is mostly grown on dry land or sand soils and need very less water. However, water stress at reproductive stage can reduce the chickpea yield. Leport et al. (2006) studied the influence of drought stress at pod formation on chickpea and found that drastically reduce seed yield in *desi* and *kabuli* chickpea types (Table 6) due to increased pod abortion. However, like salinity stress tolerance, chickpea genotypes with large number of flowers and braches can produce better yield under drought-stressed condition. Moreover, *kabuli* chickpea type is less drought tolerant than *desi* type.

The chickpea genotypes with salt and drought resistance can be successfully grown on marginal land. It can adapt to poor soil fertility and can substitute cereals in rainfed and salt-affected soils. Moreover, chickpea can improve the soil health through enhanced microbial activities and nutrient availability. Irrigation management at pod formation on these soils can improve the chickpea yield.

Sesbania

Sesbania is an important nutritive legume crop that can be grown successfully under degraded saline habitat. Moreover, it has good potential for forage production in marginal lands. In a research trial, biomass yield of sesbania was reported up to 45 t ha^{-1} $year^{-1}$ that was comparably more as compared with that obtained from alfalfa (30 t ha^{-1}) (ICBA 2013; Sattar et al. 2002). It was also found that sesbania is more salt tolerant than alfalfa and has shown its tolerance up to 8–10 dS m^{-1} (Karadge and Chavan 1983), while alfalfa can tolerate salinity up to 2.0 dS m^{-1} (FAO 2009).

Amaranth (*Amaranthus cruentus* L.)

Amaranth can be cultivated in tropical and subtropical regions with warm environmental conditions (Mposi 1999a, b). It is an annual C_4 crop has high protein contents in leaves as well as vitamins and mineral and dietary fiber (Andini et al. 2013). The leaves are a good source of certain minerals like riboflavin, niacin, ascorbic acid, calcium, and magnesium (Singhal and Kulkarni 1988a, b). Being a nutritional crop with potential to withstand against drought and salinity, an important crop should have been explored as a candidate crop for marginal lands (Chaudhari et al., 2009). Amaranth has great capacity to grow under water deficit condition as it can recover from severe drought spells. Therefore, it can be grown successfully on water deficit and marginal lands (Liu and Stützel 2002) Moreover, there is also genotypic variation in amaranth as Omami and Hammes (2006) tested *A. tricolor* and *A. cruentus* performance under salt and drought stress and found that *A. tricolor* is more salt tolerant than *A. cruentus*. Palada and Chang (2003a, b) demonstrated that amaranth can tolerate soil pH in the range of 4.5–8.0.

Table 5 Influence of salinity on grain yield of legumes

Crop	Genotype	Salinity imposition	Decrease (%) in yield over control	References
Cow pea	IT97K-573-1-1	50 mM	60.3	Taffouo et al. 2009
	IT97K-573-2-1	50 mM	36.9	Taffouo et al. 2009
	IT98K-615-6-1	50 mM	38.9	Taffouo et al. 2009
	IT99K-529-2	50 mM	49.0	Taffouo et al. 2009
	IT00K-218-22	50 mM	45.5	Taffouo et al. 2009
	IT03K-337-6	50 mM	43.2	Taffouo et al. 2009
	IT04K-227-2	50 mM	56.6	Taffouo et al. 2009
	IT04K-321-2	50 mM	41.8	Taffouo et al. 2009
	Mouride	50 mM	56.5	Taffouo et al. 2009
	Mougne	50 mM	31.3	Taffouo et al. 2009
	Melakh	50 mM	9.30	Taffouo et al. 2009
	Life Brown	50 mM	24.5	Taffouo et al. 2009
	Vita-5	50 mM	44.3	Taffouo et al. 2009
	Garoua GG	50 mM	24.0	Taffouo et al. 2009
	Garoua PG	50 mM	33.0	Taffouo et al. 2009
	Mouola GG	50 mM	46.7	Taffouo et al. 2009
	Mouola PG	50 mM	53.2	Taffouo et al. 2009
	Tsacre	50 mM	21.9	Taffouo et al. 2009
Soybean	AC Bravor	640 kg/ha NaCl	5.30	Miransari and Smith 2007
	AC Bravor	1280 kg/ha NaCl	29.7	Miransari and Smith 2007
Faba bean	ILB1814	− 0.6 MPA + 1 ds/m	44.5	Katerji et al. 2011
	ILB1814	2.3 ds/m	11.7	Katerji et al. 2011
	ILB1814	− 0.6 MPA + 2.3 ds/m	44.5	Katerji et al. 2011
	ILB1814	3.6 ds/m	18.0	Katerji et al. 2011
	ILB1814	− 0.6 MPA + 3.6 ds/m	46.1	Katerji et al. 2011
Chickpea	Tolerant genotypes	1.17 g NaCl kg^{-1} soil	31.2	Vadez et al. 2007
	Sensitive genotypes	1.17 g NaCl kg^{-1} soil	75.4	Vadez et al. 2007

Because of rapid root and shoot growth, it is proved to be an efficient user of soil moisture (Liu and Stützel 2004a, b). Amaranthus is drought tolerant as it can survive and produce significant biomass under very severe drought condition (Table 7; Chauhan and Abugho 2013). Amaranth can be grown in dry areas successfully where most of the commercial crop fails, and it also has high yield potential. For instance, Barba de la Rosa et al. (2009) reported high yield of two genotypes Gabriela (14 22 kg/ha) and DGETA (1475 kg ha^{-1}) of *A. hypochondriacus* grown on Mexican Highlands zone than maize and soybean (Table 8).

The screening and selection of salt and drought tolerant varieties of Amaranth might useful for development in marginal lands and to combat food and nutrition security (Alemayehu et al. 2015a, b). Moreover, there is need to optimize the production technology of Amaranth to evaluate it as potential alternate crop on marginal soils.

Nonlegume grain crops

Barley

Barley (*Hordeum vulgare* L.) is a cereal grain crop that was domesticated thousand years ago in Middle East. Barley grains has significant nutritious value due to the presence of antioxidant phytochemicals (total polyphenols, proanthocyanidins, carotenoids), dietary fiber, protein (14.4%), β-glucan (4.6%) contents, and insoluble bound phenolic acids represented 88.3%, and includes ferulic, salicylic, and gallic acids (Suriano et al. 2018). A significant portion of barley has been used as feed for poultry, cattle, camels, and sheep and for malting, brewing, and preparation for alcoholic and nonalcohol beverages.

It has shown excellent growth and adaptation in a variety of environment including marginal lands and has shown the

Table 6 Influence of drought stress on seed yield of grain legumes

Crop	Genotype	Drought imposition	Decrease(-)/increase (+) in yield (%)over control	References
Cowpea (short duration)	IT85F-3139	Terminal drought	− 53.9	Belko et al. 2014
	IT93K-693-2	Terminal drought	− 53.8	Belko et al. 2014
	IT97K-499-39	Terminal drought	− 56.2	Belko et al. 2014
	KVx-61-1	Terminal drought	− 55.9	Belko et al. 2014
	IT93K-93-10	Terminal drought	− 81.5	Belko et al. 2014
Cowpea (medium duration)	IT93K-503-1	Terminal drought	− 49.4	Belko et al. 2014
	IT96D-610	Terminal drought	− 51.0	Belko et al. 2014
	IT97K-207-15	Terminal drought	− 52.5	Belko et al. 2014
	KVx-403	Terminal drought	− 46.3	Belko et al. 2014
	KVx-421-25	Terminal drought	− 43.8	Belko et al. 2014
	Petite-n-grn	Terminal drought	− 77.8	Belko et al. 2014
Chickpea	Sona	Withheld irrigation 50 DAS	− 30.0	Behboudian et al. 2001
	Tyson	Drought stress at pod formation	− 66.0	Leport et al. 2006
	Sona	Drought stress at pod formation	− 73.0	Leport et al. 2006
	Kaniva	Drought stress at pod formation	− 90.0	Leport et al. 2006
	Narayen	Drought stress at pod formation	− 94.0	Leport et al. 2006
Soya bean		Natural drought + deep tillage	− 37.8	Frederick et al. 2001
		Natural drought	− 51.7	Frederick et al. 2001
	cv. Williams	80 mm evaporation	− 31.3	Sadeghipour and Abbasi (2012)
	cv. Williams	120 mm evaporation	− 57.4	Sadeghipour and Abbasi (2012)
		30% FC	− 60.0	He et al. 2017
Faba bean		500 m^3 less water than control	+ 5.90	Al-Suhaibani 2009
		1500 m^3 less water than control	− 25.3	Al-Suhaibani 2009
		3500 m^3 less water than control	− 49.4	Al-Suhaibani 2009
		4500 m^3 less water than control	− 54.1	Al-Suhaibani 2009
		5500 m^3 less water than control	− 57.9	Al-Suhaibani 2009

DAS days after sowing

ability to tolerate drought and moderate salinity. To evaluate a forage yield response towards the different levels of salinity, an experiment (both lab and field based) was carried out on 2300 accessions of Batini barley. The germination, seedling growth, and tillering was measured and found a large variation among each parameter which was attributed to difference in genetic makeup. They concluded that some of barley genotypes were stable and salt tolerant and should contribute to increasing barley production in arid and marginal environments (Al-Dakheel et al. 2012). In a field study, Jaradat et al. (2004a) reported that barley landraces from Oman (Batini 1, Batini 2, and Batini 5) were most salt tolerant genotypes from a global population of 234 Barley genotypes from Omani landraces. Furthermore, Jaradat et al. (2004b) found that Batini 4 was the most salt tolerant barley and possess long roots than all other genotypes. It is relatively more tolerant to salt stress than other cereals (Qiu et al. 2011) and can be grown successfully on marginal lands. For instance, soils with EC of 5 dSm^{-1} will be marginal for vegetable, but barley (6.8 d Sm^{-1}salinity threshold) can be grown successfully on these soils for forage production (Maas, 1990). Wild barely and its domesticated species are important feed crop in fertile crescent and covers ~ 5 million ha or drought stresses, low input marginal land (Newton et al., 2011).

Barley is mostly cultivated in semiarid or rainfed areas. It can produce good yield on water deficit soils. However, drought stress on critical growth stages like flowering and grain filling can severely reduce the barley yield (Table 9). Mansour et al. (2017) evaluated the performance of barley genotypes against drought tolerance and found that drought tolerant barley genotypes produce more biomass and grain yield (4.97 t ha^{-1} at 482 mm) with higher water use efficiency (WUE) at low water supply compared with drought-sensitive genotypes at higher irrigation level (3.51 t ha^{-1} at 561 mm) (Table 10). Moreover, barley can be grown successfully on water limited soils by better irrigation management (drip

Table 7 Influence of salinity on yield of quinoa, amaranth, chia, and teff

Species	Salt concentration	Yield reduction (%)	References
Quinoa	10 dSm^{-1}	4.35	Incekaya and Yazar, (2016)
	20 dSm^{-1}	8.96	
	30 dSm^{-1}	9.61	
	10 dSm^{-1}	+ 1.53	Maleki et al. (2018)
	15 dSm^{-1}	0.74	
	20 dSm^{-1}	18.38	
	25 dSm^{-1}	66.40	
	10 dSm^{-1}	8.89	Hirich et al. (2014a)
	20 dSm^{-1}	24.44	
	30 dSm^{-1}	33.33	
	10 dSm^{-1}	9.21	Hirich et al. (2014b)
	20 dSm^{-1}	24.04	
	30 dSm^{-1}	34.27	
	10 dSm^{-1}	16.95	Razzaghi et al., (2011)
	20 dSm^{-1}	34.78	
	30 dSm^{-1}	32.17	
	40 dSm^{-1}	29.56	
	40 dSm^{-1}	+ 6.13	Yazar et al., (2015)
	30 dSm^{-1}	15.06	
	20 dSm^{-1}	9.72	
	10 dSm^{-1}	6.85	
Amaranth cruentus	100 mM NaCl (salt stress)	66.7	Omami and Hammes (2006)
	Drought + salt [(PEG (Mw 6000) iso-osmotic to 100 mM NaCl) + salt stress 100 mM NaCl)	60.4	Omami and Hammes (2006)
Amaranth hypochondriacus	100 mM Nad (salt stress)	77.4	Omami and Hammes (2006)
	Drought + salt [(PEG (Mw 6000) iso-osmotic to 100 mM NaCl) + salt stress 100 mM NaCl)	67.7	Omami and Hammes (2006)
Chia	20 mM	69	Raimondi et al. (2017)
Chia	40 mM	76.1	Raimondi et al. (2017)
Chia	60 mM	89.8 biomass	Raimondi et al. (2017)
Teff (accessions)	8 dS/m	33.3–93.3%	Asfaw and Dano (2011)
Teff (varieties)	8 dS/m	31.6–89.5%	Asfaw and Dano (2011)

irrigation) and cultivation of drought tolerant barley cultivars (Mansour et al. 2017) and by application of irrigation water at critical stages like booting and heading. Moreover, barley can be grown in crop rotation with oats and winter rye on marginal soils (low fertility soils) (Ellmer 2008). Furthermore, yield reduction due to impact of salinity and drought are demonstrated in Tables 9 and 10. Barley can be used in crop rotation as it can help in controlling the biotic stresses (disease cycle, pest weed pressure) and also gave good biomass and grain yield under suboptimal growth condition. Moreover, barley genotypes with high tolerance against abiotic stresses need to be developed as it has potential to produce significant yield on marginal lands. It has been cultivated successfully on marginal lands and has shown adaptation for biomass and grain yield in different regions across Middle East, North Africa, East Asia, West Asia, and Mediterranean basins (Al-Dakheel et al. 2012; Jaradat et al. 2004a; Qiu et al. 2011; Saade et al. 2016; Mansour et al. 2017).

Quinoa

Quinoa is an important nutritive grain crop that has shown its potential to grow and produce good and stable yield in different marginal environments. Different genotypes of quinoa have been selected following long-term screening against salinity and drought stress and possess positive attributes in a wider global context (Jacobsen 2003a, b). Previously, quinoa crop has demonstrated high tolerance in extreme soil environment and proved as an industrial crop because it is a multipurpose cereal grain crop with a lot of benefits regarding health

Table 8 Influence of drought stress on yield of quinoa, amaranth, chia, and teff

Species	Genotype	Drought (% of water applied)	Yield reduction (%)	References
Quinoa		50	13.16	Incekaya and Yazar 2016
		75	10.47	
		25	17.61	Pulvento et al. 2013
		50	8.16	
		Progressive drought	26.52	Razzaghi et al. 2011
		65	13.80	Al-Naggar et al. 2017
		35	30.06	
		67	14.28	Yazar et al., 2015
		33	16.33	
		50	30.05	
		75	19.79	
A. cruentus		0.6 MPa	2.23-19.09	Ayodele 1999
A. hypochondriacus		0.6 MPa	8.95	
A. tricolor		PEG (Mw 6000) iso-osmotic to 100 mM NaCl	54.2	Omami and Hammes (2006)
A. cruentus		PEG (Mw 6000) iso-osmotic to 100 mM NaCl	58.1	Omami and Hammes (2006)
Chia	Chia (G8)	Rainfed	27.8	de Falco et al. 2018
Teff	Addisie	Drought stress at grain formation	48.6	
	Denkeye		54.2	Shiferaw et al., 2014
	Enatite		52.9	Shiferaw et al., 2014
	Gofarie		50	Shiferaw et al., 2014
	Gommadie		49.6	Shiferaw et al., 2014
	Manya		49.6	Shiferaw et al., 2014
	Rubicunda		41.6	Shiferaw et al., 2014
	Variegata		52.7	Shiferaw et al., 2014
	Dz-01-99		49.6	Shiferaw et al., 2014
	Dz-01-196		50	Shiferaw et al., 2014
	Dz-01-354		60	Shiferaw et al., 2014
	Dz-01-787		43.9	Shiferaw et al., 2014
	Dz-01-974		53.7	Shiferaw et al., 2014
	Dz-01-1285		42.6	Shiferaw et al., 2014
	Dz-01-1681		59	Shiferaw et al., 2014
	DZ-Cr-255		70.2	Shiferaw et al., 2014
	Dz-Cr-358		50.3	Shiferaw et al., 2014
	Dz-Cr-387		47.4	Shiferaw et al., 2014

perspectives. Quinoa seeds are rich in methionine, lysine, and threonine (amino acids) as the other cereals and legumes are lack of these ones (Repo-Carrasco et al. 2003a, b). Because of high nutrition properties, FAO called the year 2013 as "Year of Quinoa", and it also identified as a major crop for rehabilitation of marginal lands for future food security (Bazile et al. 2015a, b). In a 3-year study, Rao and Shahid (2012a, b, c) found that quinoa demonstrated good yield potential (range 53.86–359.86 g m^2 (2007–2008) and 3.32–258.42 g m^2), and adaptation for marginal lands of United Arab Emirates. The yield reported in these studies also indicates a wide genetic diversity under UAE conditions.

Quinoa is attracting the global attention due to the limitation of freshwater use, and its high tolerance to different abiotic stresses. Quinoa has also shown good performance in marginal lands of several Central Asia and MENA countries. These countries have nutrient poor sandy soil and saline water resources. In a pilot scale experiment, different quinoa genotypes were evaluated against forage and seed yield under agroecological conditions of Uzbekistan, Tajikistan, and

Table 9 Influence of salt stress on grain yield of barley

Barley Genotypes	Salinity imposition	Decrease (%) in yield over control	References
	17 dS m^{-1}	− 35.3	Saade et al. 2016
	5 dS m^{-1}	3.40	Pakar et al. 2016
	10 dS m^{-1}	24.4	Pakar et al. 2016
	15 dS m^{-1}	46.1	Pakar et al. 2016
Keel	0.75 dS m^{-1}	15.9	Harris et al. 2010
	1.5 dS m^{-1}	79.7	Harris et al. 2010
M Mundah	0.75 dS m^{-1}	35.5	Harris et al. 2010
	1.5 dS m^{-1}	68.2	Harris et al. 2010
Krichauff	0.75 dS m^{-1}	41.4	Harris et al. 2010
	1.5 dS m^{-1}	81.0	Harris et al. 2010
Janz	0.75 dS m^{-1}	23.2	Harris et al. 2010
	1.5 dS m^{-1}	75.6	Harris et al. 2010
	13 dS m^{-1}	30.7	Hammami et al. 2017
	13 dS m^{-1}	29.0	Hammami et al. 2017
	13.3 dS m^{-1}	45.4	Hammami et al. 2017
	13.3 dS m^{-1}	28.0	Hammami et al. 2017
PK-30130	4.8 dS m^{-1}	5.31	Mahmood 2011
PK-30163	4.8 dS m^{-1}	1.90	Mahmood 2011
CM72	200 mM	28.8	Ahmed et al. 2013
XZ16	200 mM	14.9	Ahmed et al. 2013
XZ5	200 mM	20.8	Ahmed et al. 2013
CM72	Terminal drought stress + 200 mM	49.1	Ahmed et al. 2013
XZ16	Terminal drought stress + 200 mM	48.6	Ahmed et al. 2013
XZ5	Terminal drought stress + 200 mM	42.9	Ahmed et al. 2013
Wild-type	1.23 dS m^{-1}	92.2	Schilling et al. 2014
35S-AVP1-1a	1.23 dS m^{-1}	62.9	Schilling et al. 2014
35S-AVP1-1b	1.23 dS m^{-1}	47.7	Schilling et al. 2014
35S-AVP1-2	1.23 dS m^{-1}	52.8	Schilling et al. 2014
35S-AVP1-3	1.23 dS m^{-1}	69.5	Schilling et al. 2014

Kyrgyzstan. The average seed yield varied in the range of 294 g m^{-2} (Q3) and 557 g m^{-2} (Q5) in Uzbekistan. However, in Tajikistan, yield was in the range of 147 g m^{-2} (Q2) to 336 g m^{-2} (Q1) (ICBA 2015). In FAO's multicountry quinoa trial, conducted during 2014; the seed yield was varied significantly across different countries and locations within the countries. In a multicountry quinoa yield trial, Dost (2015a, b) found that highest yield (7.50 t ha^{-1}) was recorded in Lebanon, followed by Egypt (3.87 t ha^{-1}), while the lowest yield was recorded in Mauritania (0.23 t ha^{-1}). The average seed yield was in the range of 0.11–0.96 t ha^{-1} (Iraq), 0.24–1.90 t ha^{-1} (Yemen), 0.41–3.87 t ha^{-1} (Egypt), 1.50–7.50 t ha^{-1} (Lebanon), 0.16– 1.56 t ha^{-1} (Iran), and 0.03–0.23 t ha^{-1} (Mauritania). Rao et al. (2013a, b) reported that quinoa yield was higher (> 2 t ha^{-1}) in two accessions Ames 13761 and NSL 106398 that was comparatively higher as compared to those reported by Bhargava et al. (2007a, b). Yield reduction is quinoa is very low even at very high salt stress (Table 7), and some genotypes of quinoa produce higher yield at 40 dS m^{-1} than control plants (Yazar et al. 2015a, b). Likewise, it has great ability to withstand drought stress (Table 8).

The above results indicate that optimization of production technology on marginal soils, irrigated with low-quality saline water is necessary in order to screen out suitable genotypes from a global collection that can survive in the harsh saline environment and should have a stable and acceptable yield potential. Therefore, tolerant quinoa genotypes should have to be developed as a candidate crop for marginal lands in order to evaluate their yield potential for food security. Quinoa has

Table 10 Influence of drought on grain yield of barley

Barley Genotypes	Drought imposition	Decrease (%) in yield over control	References
Rum	Terminal drought 50% FC	62.5	Samarah et al. 2009
	Terminal drought 25% FC	84.6	Samarah et al. 2009
ACSAD176	Terminal drought 50% FC	48.1	Samarah et al. 2009
	Terminal drought 25% FC	84.8	Samarah et al. 2009
Athroh	Terminal drought 50% FC	58.7	Samarah et al. 2009
	Terminal drought 25% FC	84.3	Samarah et al. 2009
Yarmouk	Terminal drought 50% FC	63.9	Samarah et al. 2009
	Terminal drought 25% FC	86.7	Samarah et al. 2009
	185 mm irrigation WCD	28.3	Mansour et al. 2017
	305 mm irrigation WCD	40.2	Mansour et al. 2017
	545 cm irrigation WCD	18.6	Mansour et al. 2017
	25% FC	45.2	Haddadin 2015
	25% FC	26.1	Haddadin 2015
	60% FC	49.4	Samarah 2005
	20% FC	56.9	Samarah 2005
CM72	Terminal drought (4% SMC)	63.5	Ahmed et al. 2013
XZ16	Terminal drought (4% SMC)	58.2	Ahmed et al. 2013
XZ5	Terminal drought (4% SMC)	43.1	Ahmed et al. 2013
	Drought stress at booting	35.9	González et al. 2008
	Drought stress at booting	35.1	González et al. 2008
	Drought stress at booting	38.4	González, and Martín, I. and Ayerbe, L. 1999
	Drought stress at booting	44.4	González, and Martín, I. and Ayerbe, L. 1999
	Drought stress at booting	23.7	González and Ayerbe 2010
	Drought stress at booting	27.5	González and Ayerbe 2010

FC field capacity; *WCD* whole crop duration; *SMC* soil moisture content

significant potential to adapt to several climatic environments and can tolerate to some extent drought, salinity, heavy metals, ultraviolet radiations, high temperature, and flooding and other marginal lands. This will facilitate its adaptation under climate change scenario.

Teff

Teff [*Eragrostis tef* (Zuccagni) Trotter] is a tropical cereal, and its cultivation is mainly confined to Ethiopia and Africa where it is used in food and beverages. The grain of teff is may be smallest carbohydrate rich kernel with high mineral contents and fiber and gluten free (Arendt and Zannini 2013). Due to its gluten-free status, it is becoming popular as wheat substitute for people having coeliac disease (Zannini et al. 2012). It is a low-risk crop can be grown on marginal soils as it has can grow under harsh climatic conditions and diverse ecological surrounding where other cereal crops fail (Arendt and Zannini 2013). Teff can be grown from sea level to high altitude of up to 3000 m above sea level under various rainfall conditions. However, it produces more yields in areas receiving 300 mm (Ketema 1993). Moreover, drought stress at grain-filling stage can limit the grain yield of teff. Shiferaw et al. (2012) studied the influence of drought stress at grain-filling stage in 18 teff genotypes and found a decrease of 42-70% in grain yield. Asfaw and Dano (2011), screened 10 accessions and five varieties of teff for salinity tolerance and found that accession 237186 and variety DZ-cr-37 were salt tolerant, while varieties DZ-Cr-358 and DZ-01-1681 and accession 236514 were salt sensitive. They further reported an increase in grain yield at 2 and 4 dS/m in DZ-Cr-37, 229747, and 237131. However, grain yield was substantially reduced at 8 dS/m in salt sensitive and salt intermediate genotypes. Recently Abraha et al. (2016) tested 144 teff genotypes under optimum and drought stressed conditioned, and they selected DZ-Cr-37, DZ-Cr-385, DZ-01-2053, HO-Cr-136, Dabbi, 207832, Shawa-Gemerra, and Zagure genotypes as drought tolerant due to their early maturity and high yield under moisture deficient condition while genotypes (DZ-Cr-387, DZ-01-787, DZ-01-3186, 9432, 9403, 9415, 205917, 205896, 215678, 213237, Jano, Kaye-Agachew, Purpurea, Kaye-Murri, and Dschanger) produced high yield with increased lodging resistance under normal condition. These genotypes can be used to develop teff cultivar with higher yield under drought stressed condition. In many studies, teff variety DZ-Cr-37 has been used in low rain fall areas which are susceptible to terminal drought as it is proposed to be drought tolerant with high adaptability under diverse climatic condition (Ayele et al. 2001; Cannarozzi et al. 2014; Abraha et al. 2016). Development of salt and drought tolerant genotypes that have capacity to adapt the marginal lands might help to improve the crop diversification on marginal lands.

Sorghum

Sorghum, members of the grass family, is native to Africa, and it is considered an important nutritional crop. Sorghum is now cultivated over the world mainly in developing countries such as China, Central and South America, Africa, South Africa, India, and Indonesia (Mann et al. 1983) (Fig. 4c). Sorghum genus includes several annual and perennial species (approx. 3000). The most important one is *Sorghum bicolor* (L), Moench, sin. *Sorghum vulgare* Pers, with Sorghum *bicolor* var. *eusorghum* or grain sorghum, *Sorghum b.* var. technicum or broom sorghum, (c) *Sorghum B.* var. *saccharatum* or sweet sorghum and (d) *Sorghum b.* var. *sudanese*, or feed sorghum varieties. In Africa and India, the grain is used as food, because it is, like other cereals, a good source of starch, sugars, protein, and phenols that confer it not only nutritional quality but also important beneficial effects on human health. Because of the slow release of sugars than other cereals decreasing detrimental effects in diabetic diseases, the phenolic acids and flavonoids have important anticarcinogenic and antioxidant properties (Awika and Rooney 2004). Being a gluten-free cereal, sorghum importance is growing in all the developed countries in where the occurrence of celiac disease (CD) is sharply rising. The incidence of CD was a little bit higher (from 1:22 to 1:39), for the first- and second-degree relatives of CD patients and 1:56 for patients having either gastrointestinal symptoms or a disorder associated with CD, in USA (Accomando and Cataldo 2004). In Europe, the prevalence of CD is 1:100, and this number is set to rise. Sorghum is a good source of crude fat (3%) and vitamins D, E, and K, B-complex. Sorghum showed significant quantity of thiamin, riboflavin, and niacin. Sorghum has several nutraceutical properties, and its use in food industry for producing malted and distilled beverages (beer, low-alcohol drinks) and popped grains.

Sorghum is in fact a plant with a well-developed root system that growing longer than 1 m explains its inclined resistance to thermic stress compared with others cereal crops. Sorghum has adaptation potential to cultivate in arid and semi-arid areas where annual rainfall is around 100 mm (Assefa et al. 2010). Sorghum pollen can tolerate higher temperature (45–50 °C). The crop can be cultivated in sandy and nutrient poor soils (pH range 4.5–8.5) because of its low fertilizer requirements for growth, development, and reproductive stage. Sorghum is nowadays commercially in both developed and developing countries (FAOSTAT 2012). Intensive sorghum systems are highly mechanized, use hybrid seed and

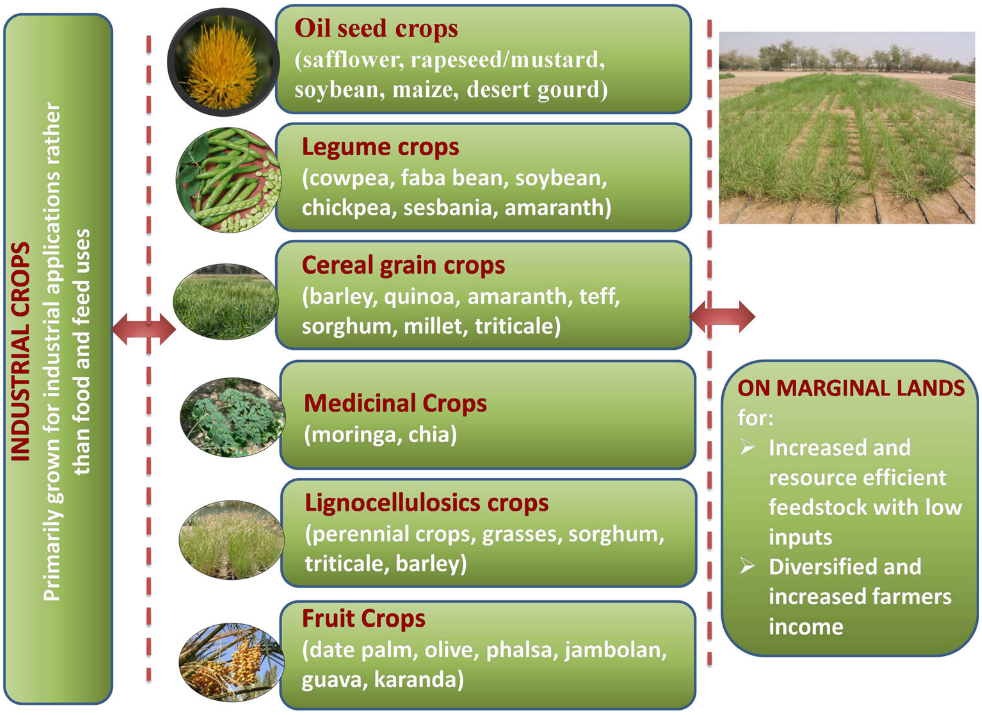

Fig. 4 Diversified and specialty group of crops (oil seeds, legumes, cereals, medicinal crops, lignocellulose, and fruit crops) that has the capacity of adaptation to tolerate salinity and drought and are suitable for cultivation in marginal environments with proper agronomic and management practices

fertilizers, and are either no-till with herbicide or mechanized tillage. Sorghum yields range from 3 to 5 metric tons per ha under intensive cultivation, as compared with more extensive smallholder systems which average 0.5 to 1.0 metric tons per ha (Clay 2004). Nevertheless, the tendency to grow sorghum on marginal and heavily sloped lands does pose some environmental risks—including soil degradation and erosion—that can be mitigated through the adoption of best practices. Early sorghum hybrids exhibited a 40% yield advantage over open pollinated varieties (Duvick 1999). In South Africa to some extent, this intensification has already occurred.

Sorghum is a multipurpose industrial crop that has shown high tolerance against salinity and is very suitable for saline and marginal lands (Rao et al. 2015). Sorghum, a C4 crop, is normally a tall annual grass with adventitious root system has been proved to be useful for grain as well as forage production (Harada et al. 2000). In USA, different varieties of sweet sorghum can be used as fodders and development of hybrid fodder. Once established, the sweet sorghum has shown the salinity tolerance potential (Cook et al. 2005a, b) while other workers also described the sorghum as highly salt-tolerant crop plant (Fahmy et al. 2010). Balole and Legwaila (2006) reported that forage sorghum produced an average of 20 t ha^{-1}that might be reached at 75 t ha^{-1}under favorable growth conditions. Sorghum should have to be promoted in water scare regions because it needs less water during growth period and to reach to reproductive stage. Thus, sorghum is very suitable in drought prone area and areas with declining aquifers (Rao et al. 2015). In a long-term screening, selection, and development of salt tolerant genotypes, Krishnamurthy et al. (2007) screened seven genotypes that showed tolerance against salinity under field conditions. Influences of salinity and drought on the yield of sorghum genotypes are shown in Tables 11 and 12.

In India, 75% of sorghum is already of high-yielding varieties (Pray and Nagarajan, 2009). But despite the increasing global awareness of plant genetic resources and links to food security, sorghum is relatively neglected in scientific research, agricultural programs, and policies (Garí 2002). In South Africa, sorghum is grown either as a rainy season crop or as a postrainy season crop. The highest sorghum yields are achieved with the rainy season crop (around 1 ton/ha) due in large part to abundant water access—sorghum will also tolerate poorly drained soils and can survive temporary waterlogging during the rainy season (Fageria 2011). Drought still poses a threat to rainy season sorghum, however, particularly in years of midseason drought. The postrainy season crop is even more drought constrained as the crop is dependent upon postrainy season stored soil moisture (Murty et al., 2007). In addition to direct impacts on the plant, drought can lead to reduced nutrient uptake and make sorghum more susceptible to pests (Assefa et al. 2010). Efforts to overcome water constraints on sorghum production in smallholder systems focus on improved water management, planting timing, and using diverse and drought-resistant varieties. In both SA and SSA, optimizing planting dates for sorghum to prevent water stress during water-sensitive growth periods is another key strategy to mitigate sorghum yield reductions (Assefa et al. 2010). Singh et al. (2016) identified late sowing and low water-holding capacity of shallow soils as the key impediments to expanded sorghum productivity in India. Depending on the local situation, making maximum efforts to prepare land early and plant the crop as early as possible with the first rains can boost crop production. It also considered a good strategy to use local varieties that are often better adapted to drought conditions than commercial varieties. However, local varieties are often lower yielding and typically do not perform as well under optimal growing conditions (Yadav, 2010). Sorghum researches have been focused on plant breeding for drought tolerance and for early maturation (Assefa et al. 2010). While poor soil fertility is a significant constraint to sorghum production, very few smallholder farmers in SSA and SA use fertilizer (and even more rarely are inorganic fertilizers applied on sorghum and millet plots). Moisture deficiencies during crop growth inhibit nutrient uptake, making fertilizer application even less beneficial and economical. Clay (2004) reported that while some smallholder sorghum farmers have invested in hybrid improved seeds such as in India, fertilizer use remains uncommon. In contrast, in developed countries—and in some intensive commercial operations in South Asia—major increases in dryland yield have been attributed to increased fertilizer use and hybrid seed advancement (Assefa and Staggenborg 2010). Similar to other crops, soil quality, and sorghum yields are higher in sorghum production systems where plant foliage remains in the field as a mulch following harvest—practice relatively more common when the crop is grown for grain rather than silage (Meyer et al. 1999). While mulching can mitigate the nutrient-depleting effects of repeated cropping and short fallows, households often prefer to use mulch for building material, fuel, and fodder (Wezel, 2000). Cover crops, crop rotation, and continuous farming along with green manure can further reduce the fertilizer and water requirements of sorghum crops (Clay 2004) or both sorghum production, conservation till age and no-till agricultural practices have been shown to reduce erosion by up to 80% (Meyer et al. 1999). Sorghum plant matter is particularly beneficial to soil if it is chopped at the time of harvesting. Weeds are a primary constraint to sorghum production (Estep et al. 2011; Waddington et al. 2010). Pests and diseases caused especially by fungi, viruses, bacteria, and nematodes sorely limit the sorghum production (Clay 2004). Grain molds lead to important decrease in sorghum grain yield and quality, especially in areas in which ameliorated cultivars have been used. The grain mold problem is due to the arrival of late rains after grain fill. A wide variety of herbicides and pesticides are also used on sorghum crops in intensive

Table 11 Impact of salt stress on quality and composition of sorghum

Sorghum bicolor L. Moench	Salinity imposition	Quality indicator	Decrease (−)/increase (+) over control	References
Sorghum bicolor L. Moench	80 mM NaCl	Dry weight	− 20%	Roy et al. 2018
Sorghum bicolor L. Moench	Sea water 50%	Shoot length	− 50%	Bafeel 2014
Sorghum bicolor L. Shallu	Salt solution (NaCl and CaCl$_2$ at 2:1 molar ratio (EC 10 dS m-)	Dry weight	− 18%	Sun et al. 2014
Sorghum bicolor L. Desert maize	Salt solution (NaCl and CaCl$_2$ at 2:1 molar ratio (EC 10 dS m^{-1})	Dry weight	− 20%	Sun et al. 2014
Sorghum bicolor L. Macia	Salt solution (NaCl and CaCl$_2$ at 2:1 molar ratio (EC 10 dS m^{-1})	Dry weight	− 70%	Sun et al. 2014
Sorghum bicolor L. Sandalbar	NaCl (EC10 dS m^{-1})	Total protein	− 10%	Kausar et al. 2014
Sorghum bicolor L. Sandalbar	NaCl (EC10 dS m^{-1})	Total free amino acids	+ 50%	Kausar et al. 2014
Sorghum bicolor L. JS-2002	NaCl (EC10 dS m^{-1})	Total protein	− 15%	Kausar et al. 2014
Sorghum bicolor L. JS-2002	NaCl (EC 10 dS m^{-1})	Total free amino acids	+ 55%	Kausar et al. 2014
Sorghum bicolor L.	NaCl 50 mM	Total phenols	+ 50%	Sailaja and Sujatha 2013
Sorghum bicolor L. Soave	NaCl 60 mM	Sucrose, glucose, fructose	(+ 50%, − 10%, − 60%)	Almodares et al. 2008
Sorghum bicolor L. Sofra	NaCl 60 mM	Sucrose, glucose, fructose	(+ 98%, − 70%, + 150)	Almodares et al. 2008
Sorghum bicolor L. Soave	NaCl 90 mM	Sucrose, glucose, fructose	(+ 63, − 36%, − 36%)	Almodares et al. 2008
Sorghum bicolor L. Sofra	NaCl 90 mM	Sucrose, glucose, fructose	(− 30%, − 50%, + 278%)	Almodares et al. 2008

production systems, especially in SA (Clay 2004; Khan et al. 2000). Literature on environmental impacts of pest management practices specific to sorghum production is limited up to now. Herbicides and pesticides regularly used on intensive sorghum crops have been shown to cause harm to surrounding ecosystems (Clay 2004; Ragnarsdottir 2000; Kamrin 1997), but few data are available for sorghum yet.

Sorghum is a cereal that could be easily adapted to stress conditions reducing only in part its growth and nutritive properties mainly in respect to the cultivar used. The different cultivars adopt different mechanism for salt stress tolerance increasing the production and the accumulation of organic solutes. Sorghum is really appreciated for its nutritional properties and agronomic advantages mainly in arid and semiarid environments. Sorghum grains are an important source of gluten-free flour making it suitable to hundreds of gluten intolerant populations. Sorghum flour combined with flours from other cereals and legumes can be an important opportunity for ameliorating its nutritional value. Food processing represents also an economic benefit for this cereal. Research on how different processing can affect sorghum nutritional properties could help spread consume of sorghum as food.

Millets

Millets are highly variable small grain annual crops cultivated (Kothari et al. 2005) in temperate, subtropical, and tropical regions with low-input supply and mostly grown in harsh environments (salinity, low soil fertility, drought, heat, and chilling stresses). They play important role in ensuring food security to poor people in semiarid tropics due to low cultivation of major food crops owing to poor soil fertility and low precipitation (Das and Rakshit 2016). Pearl millet, finger millet, proso millet, and foxtail millet are the most cultivated species used as food, feed, and fuel (Hithamani and Srinivasan 2014) (Fig. 4d). All millets other than sorghum and pearl millets are called small or minor millets. Pearl millet represents more than half of global millet production. Proso millet is used as a feed for birds in developed countries and as food in parts of Asia. The foxtail millet is more utilized as food in China and in Europe. The other species (aia, kodo and small millet, fonios, and teff) are instead more used locally in small countries as food grains. The different species differ from one another, due to their physical characteristics, growth duration, quality, and adaptation to soil and climate. For the nutrient and protein content, millet can be considered equivalent or better

Table 12 Impact of drought stress on physiological and biochemical attributes of sorghum

Sorghum bicolor L. Moench	Osmotic stress	Quality indicator	Decrease (−)/increase (+) over control	References
Sorghum bicolor L. Moench	PEG 10%	Biomass	− 25%	O'Donnell et al. 2013
Sorghum bicolor L. Moench	PEG 20%	Biomass	− 50%	O'Donnell et al. 2013
Sorghum bicolor L. Shallu	PEG 10%	Photosynthesis (NAR)	0%	O'Donnell et al. 2013
Sorghum bicolor L. Desert maize	PEG 20%	Photosynthesis (NAR)	− 50%	O'Donnell et al. 2013
Sorghum bicolor L.	PEG 31%	Total Sugar	+ 50%	Gill et al. 2001
Sorghum bicolor L.	PEG 31%	Reducing Sugar	+ 50%	Gill et al. 2001
Sorghum (cv. Liao waxy No. 3)	PEG 20%	Total Chlorophyll	− 28%	Zhang et al. 2015
Sorghum (cv. Liao waxy No. 3)	PEG 20%	Soluble Protein	+ 32%	Zhang et al. 2015
Sorghum (cv. Liao waxy No. 3)	PEG 20%	Free amino acids	+ 50%	Zhang et al. 2015
Sorghum (cv. Liao waxy No. 3)	PEG 20%	Reducing sugars	+ 25%	Zhang et al. 2015

than wheat, rice, corn, and sorghum. Millets are enriched in proteins, vitamins especially vitamin A, and oil content that is better than maize grain oil (Nambier et al., 2011). As compared with other cereals, it is less susceptible to insects and pests. Additionally, millets are considered the most suitable crops for agriculture and food security on lands with low fertility. Millets are able to easily grown on low fertility and sandy soils in which other cereal crops produce low yields (Amadou et al. 2013; Changmei and Dorothy 2014). Millet is gaining attention in designing the modern foods because it is a gluten-free cereal which is rich in polyphenols and other biological active compounds with beneficial effects on human health. Due to the increased awareness regarding its health promoting compounds, and its ability to grow in adverse environmental conditions (drought, salinity, and high temperature), millet represents a good alternative to traditional cereals such as wheat and rice to be cultivated mainly in marginal lands. Millet has nutritive properties equal or superior to the major cereals (Leder 2004), and its nutritional properties change in respect to the variety to the climatic conditions and the soil on which it is grown. The average carbohydrates content of millets varies from 56.88 to 72.97 g/100 g, the minor amount was found in barnyard millet. The average protein content of all the millets range between 10 and 11%, except for finger millet, in which protein ranges from 4.76 to 11.70 g/100 g. Proso millet is the variety that contains the highest amount of proteins. The lipid content in all millets are similar to the other cereals; finger millet contains the lowest lipid amount while pearl millet has the highest amount of lipid. Little millet (*Panicum sumatrense*) and kodo millet (*Paspalum scrobiculatum*) contain the highest dietary fiber (785% higher than rice and wheat); this makes millets a food suitable for diabetic people (Chandel et al. 2014). Millets contain significantly higher amount of calcium and mineral than other cereals (Pontieri et al. 2014). Barnyard millet and pearl millet are richer in iron than the other millet varieties and other cereals. Millets contain also high amount of β-carotene and B vitamins especially riboflavin, niacin, and folic acid. Millets contain also a great amount of flavonoids and phenolic compounds (Chandrasekara and Shahidi 2011). Millet also possesses different secondary metabolites that have shown therapeutic and pharmacological potential. Several millet genotypes showed antioxidant, antimutagenic, antiestrogenic, antiinflammatory, and antiviral effects (Devi et al. 2014). Total antioxidant capacity of finger, little, foxtail, and proso millets resulted high for their high content of total carotenoid and tocopherol (Dykes and Rooney 2006). Millet is able to grow in presence of salinity but at different extent depending on the salt concentration and millet variety. Kumari and Vishnuvardhan (2013) showed a different response of 3 diverse accessions (IC426676, IC382888, and IPS 145) of Kodo millet to NaCl salinity. They demonstrated that all the 3 accessions germinated and grew at 50 mM NaCl, but increasing salinity germination percentage and seedling growth decreased. The accession's most resistant to salinity was IC 426676 which is able to germinate and grow at 150 mM NaCl with a short decrease also in the amount of total protein. The production of biomass and grains in field in presence of salinity depended on the genotypes and accessions. Khan et al. (2000) examined 8 varieties of millet demonstrating that at 8 dS/m, only a reduction of 20% in all the studied varieties was observed. Increasing salinity a progressive decrease in biomass was detected. The production of grain decreased increasing salinity. The greatest decrease was observed at 16 dS/m, but for up to 8 dS/m, a 20% reduction was observed. Although, in general, millets are able to grow better than cereals in semiarid environments, drought or inadequate moisture represents a threat affecting productivity. Studies in pearl millet showed that drought caused yield loss in respect to the variety and the duration of the stress. Pearl millet productivity and growth were less affected by drought conditions instead little millet productivity was decreased by drought stress conditions. The effects of salinity and drought on yield of millet are shown in Tables 13 and 14.

Millet adapt to diverse intensity of drought and salinity from seed germination to growth. Many species are able to germinate and grow on arid lands also in extreme drought and salinity conditions without modifying their nutritional values. Millet environmental adaptability determines the numerous plants per unit of area, allowing the extension of this plant to drier and salinity areas.

Triticale

Triticale is a human made hybrid cereal grain, obtained from crossing wheat and rye (Zhu 2018) (Fig. 4e, f); it is self-pollinating (similar to wheat) and not cross pollinating (like rye). It combines the best properties of both its parents, inheriting the most of wheat's qualities important for food products, and the most of rye's properties which confer resistance to disease, tolerance to drought, hardiness, and adaptability to "hard" soils. The first varieties had spring wheats as parents easily killed by low temperatures. Subsequently, winter wheats have been used as parents, producing varieties with good winter resistance. For instance, recent publications evidenced that spring triticale is a vital drought tolerant crop in North Africa and play a significant role in alleviating poverty for many needy families in some developing countries. Forage yield was reported in the range of 5.6–10.9 t ha^{-1} and grain yield between 2.2 and 5.6 t ha^{-1} (ICBA 2013). After a long-term salinity trails conducted over years at ICBA, in order to identify salt tolerant accession among a large population, the accession PI 429166 had excellent grain yield and dry matter production. The highly productive winter-type triticale can instead be successful cultivated in cold and wet environment of Northern Europe.

Triticale is grown on about 3 million ha in the world (FAO, 2003), and it is widely used as forage in farming system even if triticale grain contains vitamins, mineral nutrients, and proteins in concentration similar to wheat and rye. For these reasons, triticale should be highly recommended as food, mainly because both spring and winter varieties on average contain 10% of proteins, 56% of carbohydrates 2.8% of crude fibers, 4% of free sugars, and 1.6% of ash, representing a valid alternative to wheat and rye mainly in area where these two species have difficult to grow. Triticale is grown in areas with an annual average rainfall ranging from 300 to 900 mm. Very little triticale is irrigated. Triticale for grain is generally sown in autumn and harvested in summer time. Triticale was able to grow under salinity and drought stress conditions and numerous works evidenced that triticale lines were better than wheat cultivars for resistance to drought taking in account grain yield and majority of physiological traits. Giunta et al. (1993) confirmed that triticale genotypes were more drought tolerant than wheat and there was slight reduction in its grain yield. Wheat production decreased significantly (by 25, 54, and 87%) under drought stress, while triticale slightly or nonsignificantly decreased its yield (by 8%) in comparison with the irrigated control, evidencing a greater drought tolerance of triticale attributable to the greater ability of its roots to absorb water from soil. Akbarian et al. (2011) found an inverse and significant relationship between grain yield loss due to drought stress and proline content. These findings provided evidences on the key role of proline in inducing tolerance to drought stress.

Proline was also evaluated in 18 lines of triticale under salinity (16 dS m^{-1}), and the results showed an inverse and significant relationship between grain yield loss under salinity and proline content confirming its key role in alleviating abiotic stress in plants (Salehi and Arzani 2014). Akgun et al. (2011) evidenced that high salinity levels (25 dS m^{-1})

Table 13 Impact of salt stress on different genotypes of millets

Millet genotypes	Salinity imposition	Quality indicator	Decrease (−)/increase (+) over control	References
Kodo millet IC 426676	150 mM NaCl	Germination rate	− 40%	Kumari and Vishnuvardhan 2013
Kodo millet IC382888	150 mM NaCl	Germination rate	− 80%	Kumari and Vishnuvardhan 2013
Kodo millet IPS 145	150 mM NaCl	Germination rate	− 90%	Kumari and Vishnuvardhan 2013
Kodo millet IC 426676	150 mM NaCl	Total protein	− 25%	Kumari and Vishnuvardhan 2013
Kodo millet IC 382888	150 mM NaCl	Total protein	− 60%	Kumari and Vishnuvardhan 2013
Kodo millet IPS 145	150 mM NaCl	Total protein	− 75%	Kumari and Vishnuvardhan 2013
Finger millet VL-315	Saline water 6 dS/m	Grain protein	− 10%	Agarwal et al. 2016
Finger millet local hills	Saline water 6 dS/m	Grain protein	− 20%	Agarwal et al. 2016
Finger millet VL-315	Saline water 14 dS/m	Grain protein	− 35%	Agarwal et al. 2016
Finger millet local hills	Saline water 14 dS/m	Grain protein	− 50%	Agarwal et al. 2016

Table 14 Impact of drought stress on different genotypes of millets

Millet genotypes	Drought	Quality indicator	Decrease (−)/increase (+) over control	References
Pearl millet Monyaloti	PEG -1.47 MPA	Stomata density abaxial	− 20%	Vijayalakshmi et al. 2012
Pearl millet GCI	PEG -1.62 MPA	Stomata density abaxial	0%	Vijayalakshmi et al. 2012
Pearl millet Monyaloti	PEG -1.47 MPA	Stomata density adaxial	− 15%	Vijayalakshmi et al. 2012
Pearl millet GCI	PEG -1.62 MPA	Stomata density adaxial	− 30%	Vijayalakshmi et al. 2012
Pearl millet IGMH 356	Water in soil 5%	Proline	+ 250%	Vijayalakshmi et al. 2012
Pearl millet IGMR 356	Water in soil 5%	Proline	+ 180%	Vijayalakshmi et al. 2012
Pearl millet ICMB 88004	Water in soil 5%	Proline	+ 50%	Vijayalakshmi et al. 2012
Pearl millet IGMH 356	Water in soil 5%	Total sugars	+ 100%	Vijayalakshmi et al. 2012
Pearl millet IGMR 356	Water in soil 5%	Total sugars	+ 80%	Vijayalakshmi et al. 2012
Pearl millet ICMB 88004	Water in soil 5%	Total sugars	+ 50%	Vijayalakshmi et al. 2012
Pearl millet	PEG 6000 (− 1.0 MPA)	shoot length	− 44%	Radhouane 2007
Pearl millet	PEG 6000 (− 2.0 MPA)	shoot length	− 84%	Radhouane 2007
Pearl millet	PEG 6000 (− 1.0 MPA)	Root lenght	+ 18%	Radhouane 2007
Pearl millet	PEG 6000 (− 2.0 MPA)	Root lenght	− 88%	Radhouane 2007

decreased seed germination (− 50%) of 5 triticale genotypes obtained from the CIMMYT while increased proline levels. Kaydan and Yagmur 2008 evaluated seed germination and seedling growth of triticosecale Witm. cv. Presto under osmotic stresses caused by water and NaCl. Their results evidenced that water stress, at the same osmotic potential of salt, was more detrimental than salinity compared. They compared different varieties having different seed size and highlighted that seed with greater size resisted more to salinity than seeds with smaller size. Lirong et al. (2016) tested eight varieties of triticale for drought resistance using 20% polyethylene glycol 6000. Their results showed that the seedling fresh weight of all varieties decreased, MDA content increased, proline content, and soluble sugar content increased with water stress. Soluble protein contents raised in some varieties while decreased in some others. The activity of SOD increased, and POD, CAT activity variations were different in all the 8 varieties. After a comprehensive analysis, we can conclude that the drought resistance depended mainly on the varieties and less on the entity of stress. Table 15 and 16 demonstrate influence of salinity and drought on yield of Quinoa, Amaranth, Chia, and Teff.

Medicinal Crops

Chia

Chia (*Salvia hispanica* L.,) is an ancient food rich in ω-3/-6 fatty acids, insoluble fiber, protein, minerals, and antioxidants (Orona-Tamayo et al. 2017). Its seed contain antibiotics phenolics and terpenoids that make it medicinally important plant (Baricevic and Bartol 2000). Chia is commercially grown in Bolivia and Paraguay; nonetheless, during last 15 years, its area also expanded in Argentina, Australia, and Mexico due to high economic return (8-12000 USD/ton) (Peperkamp 2014). The increase in area under Chia is due to its ability to produce significant yield on marginal lands and low-input condition. Under low-input condition, it can produce around 600 kg/ha, with some growers have reported upto1200 kg ha^{-1} under suboptimal growth condition (Coates 2011). However, in normal soil with optimal input supply 2500 kg ha^{-1} has also been reported (Cahill 2003; Ullah et al. 2015).

Chia can be good alternative crop under marginal growth conditions as it can grow on semiarid (Bochicchio et al. 2015) and acidic soils (Muñoz et al. 2013). It performs best on sand soils and is adapted to low nutrient supply (Yeboah et al. 2013). However, it has less resistant to salinity (Heuer et al. 2002) as reduction of 69, 76.1, and 89.8% in biomass of chia was observed at 20, 40, and 60 mM salt stress respectively (Table 8). It can produce good yield even under high summer temperature and drought condition (Win et al. 2018) as Chia planted in spring March and April produced 32.2 and 27.9% less yield than may planted crop. Baginsky et al. (2016) studied influence of climate on chia production in three distinct regions and found that Chia produced maximum yield (> 2900 kg ha^{-1}) under desert condition of Valle de Azapa (VA) and Canchones (CH). Chia is sensitive to low temperature as can cause significant yield reduction. Tables 8 and 9 demonstrate influence of salinity and drought on yield of quinoa, amaranth, chia, and teff. Chia is a good option for crop diversification on dry, sandy soil, and high temperature environment; it got attention in recent years. Development of salt sand chilling resistant chia genotypes will help to improve the crop diversification on marginal land, as it is very low input

Table 15 Impact of salt stress on different triticale genotypes

Triticale genotypes	Salinity imposition	Quality indicator	Decrease (−)/increase (+) over control	References
Karma-2000	14.9 dS/m NaCl	Germination %	− 16%	Akgun et al. 2011
Triticale 4	19.3 dS/m NaCl	Germination %	− 42%	Akgun et al. 2011
Triticale 43	25 dS/m NaCl	Germination %	− 58%	Akgun et al. 2011
Karma-2000	14.9 dS/m NaCl	Proline	+ 2300%	Akgun et al. 2011
Triticale 4	19.3 dS/m NaCl	Proline	+ 1500%	Akgun et al. 2011
Triticale 43	25 dS/m NaCl	Proline	+ 855%	Akgun et al. 2011
Triticosecale Wittm	12 dS/m NaCl	Shoot biomass	− 60%	Yousfi et al. 2010
Triticosecale Wittm	17 dS/m NaCl	Shoot biomass	− 70%	Yousfi et al. 2010
Hexaploid triticale	16 dS/m NaCl	Gliadin/glutenin	+ 20%	Salehi and Arzani 2013
Hexaploid triticale	16 dS/m NaCl	Carbohydrates %	− 3%	Salehi and Arzani 2013

requiring crop and can grow under limited water supply and withstand high temperature.

Moringa

Moringa (family Moringaceae) is an Old-World dry tropical plant genus with 13 species that has shown great potential in terms of food, feed and pharmacopeia. Three species of Moringa have shown great potentials to be suitable feedstock for sustainable production of biodiesel. These are *Moringa oleifera* (Atabani et al., 2013), *Moringa stenopetala* (Ejigu et al., 2010) and *Moringa peregrina* (Salaheldeen et al., 2015). In the UAE, two *Moringa* tree species are growing the exotic *M. oleifera* which is cultivated as ornamental plants in the UAE and the native *M. peregrina*, which is growing naturally in the mountains of the UAE. Several colleagues reported that *M. oleifera* has significant nutritional benefits and is a proven source of animal forages. Meanwhile, it is quite suitable for cultivation to nutrient poor saline and marginal lands with low water and nutrient availability (Nouman et al., 2014). Ayerza, (2011) indicated that *M. oleifera* has oil productivity of 580 kg ha^{-1}. This indicates this *M. oleifera* could be cultivated economically in subtropical regions of the world (Salaheldeen et al., 2014). The whole Moringa tree is a good alternate source of pharmaceutical agents and antioxidant and has nutritional feedback.

It has wood that is good for firewood and charcoal and also resists termites. Al-Kahtani, (1995) reported 12.4% moisture, 53.9% oil, 23.2% protein, 12.1% dietary fibers, 17.5% carbohydrate, and 2.6% ash. However, the oil content of the exotic *M. oleifera* seeds was recorded as 34.8% (Anwar and Rashid 2007) in the dry seeds. Polyunsaturated fatty acids, amino acids, and sterols can be obtained from *M. peregrina* seeds (Al-Dabbas 2010). Salaheldeen et al. (2015) converted the

Table 16 Impact of drought stress on different Triticale genotypes

Triticale genotypes	drought imposition	Quality indicator	Decrease(-)/increase (+) over control	References
Triticale lines	− 1.5 MPa	Proline	+ 50%	Shanazari et al. 2018
Triticale lines	− 1.5 MPa	MDA	+ 20%	Shanazari et al. 2018
Triticale lines	− 1.5 MPa	Carotenoids	+ 10%	Shanazari et al. 2018
Triticosecale Wittmack	Natural drought	Final grain weight	− 12%	Royo et al. 2000
Triticosecale Wittmack	Natural drought	Grain volume	− 8%	Royo et al. 2000
Moreno	− 1.2 MPa	Leaf area	0%	Lombani and Arzani 2011
Lasko	− 1.2 MPa	Leaf area	0%	Lombani and Arzani 2011
Prego	− 1.2 MPa	Leaf area	+ 10%	Lombani and Arzani 2011
Alamos 3	− 1.2 MPa	Leaf area	+ 10%	Lombani and Arzani 2011
Moreno	− 1.2 MPa	Number of stomata	+ 10%	Lombani and Arzani 2011
Lasko	− 1.2 MPa	Number of stomata	0%	Lombani and Arzani 2011
Prego	− 1.2 MPa	Number of stomata	+ 10%	Lombani and Arzani 2011
Alamos 3	− 1.2 MPa	Number of stomata	+ 15%	Lombani and Arzani 2011

crude oil of *M. peregrina* to biodiesel by the transesterification reaction, catalyzed by potassium hydroxide and got high ester content (97.79%). Sharma et al. (2009) have reported that Moringa oil exhibited the highest thermooxidative stability, compared with other vegetable oils, such as Jatropha oil, cottonseed oil, canola oil, and sunflower oil (Sharma et al. 2009).

Lignocellulosics crops

Perennial forage grass

Cenchrus ciliaris L. is an important forage plant that can be grown in drought and saline affected marginal lands. It can be cultivated in different arid and semiarid areas of Asia, Africa, and Australia (Arshadullah et al. 2011). It is C_4 plant and is valued for palatable forage and intermittent grazing. Al-Dakheel et al. (2015) reported that the dry matter yield varies from 24.5 to 73.0 t ha^{-1} at 15 dS m^{-1}). However, the biomass yield varies from 26.3 to 65.8 t ha^{-1}among the top five genotypes at 15 dS m^{-1}. These screen and selected accessions of *C. ciliaris* are a good forage source for animals in arid and semiarid regions. Meanwhile, Al-Dakheel and Hussain (2015) demonstrated that genotype Grif 1619 was the highest dry matter yielding accession at 15 dS m^{-1}.

Fruit crops

Some fruit crops have shown promising potential and adaptation under marginal environment. The prominent fruit crops that can be grown in saline and marginal lands include date palm (*Phoenix dactylifera* L.), olive (*Olea europaea* L.), phalsa (*Grewia asiatica* L.), chicle (*Manilkara zapota* (L.) P. Royen), guava (*Psidium guajava* L.), jambolan (*Syzygium cumini* L.), Indian jujube (*Ziziphus mauritiana* Lam.), Indian gooseberry (*Phyllanthus emblica* L.), and karanda (*Carissa carandas* L.) (Maas and Hoffman, 1977; Qureshi and Barrett-Lennard, 1998). The performance of two important fruit trees (date palm and olives) are summarized here.

Date palm

Date palm (*Phoenix dactylifera* L.), is an important nutritive fruit crop, rich in minerals, nutrients, and carbohydrates. The fruit tree has the capacity to tolerate harsh climate, marginal environment drought, high temperature, and salinity (12.8 dS m^{-1}) (Ramoliya and Pandey 2003). According to the study of Aljuburi (1992), the Lulu cultivar was more sensitive than other three tested varieties (Khalas, Barhee, Boman) at different salinity levels (0, 0.6, 1.2, and 1.8%). According to reports of Kurup et al. (2009), date palm can tolerate the salinity up to a certain level of threshold. Ramoliya and Pandey (2003) demonstrated that date palm is tolerant to salinity up till 12.8 dS m^{-1}. Meanwhile, several seed germination, growth, and physiological features showed tolerance against salt stress in the range of 4.3–12.8 dS m^{-1} while higher salinity reported to be lethal at different growth stages. In seedling growth bioassays, the variety Nakhla hamra showed enhancement in epicotyl length, root growth, and proline contents under drought condition imposed by PEG. While other variety Tijib showed more tolerance against salinity based on physiological and biochemical indicator (Djibril et al. 2005). Al Kharusi et al. (2017) evaluated salinity tolerance potential among 10 date palm seedlings and subjected them to 240 mM salt stress. They showed that photosynthesis, electrolyte leakage, and the shoot K+/Na+ ratio were reduced in the susceptible cultivars while Manoma and Umsila were reported as resistance cultivars. Date palm varieties, Deglet Noor', and 'Medjool showed poor performance against salinity (24000–520 ppm) and their growth; leaf development was highly decreased under salt stress (Furr and Ream 1968). From research trials of Aljuburi (1992), seedling growth, development, and leaf elongation were inhibited at all levels of salinity (0, 0.6, 1.2, and 1.8%) in different date varieties. He concluded that Lulu variety was more tolerant to salinity as compared with other varieties.

Several plasticity traits such as photosynthesis, gas exchange measurements, chlorophyll a/b ratio, ribulose 1,5-bisphosphate activity, ionic accumulation in leaves especially Na^+ and K^+, and electrolyte leakage might be used as stress biomarkers to elucidate the salinity in date palm seedlings (Youssef and Awad 2008). They found that seedlings accumulated a significant amount of salts in their foliage parts following salinity treatments. Al-Wali et al. (2011) documented that tissue culture based Khalas variety was significantly affected in terms of seedling growth and development, and response was different in pots added with or without mulch. The mechanism of salinity tolerance in date palm is not well clear. However, Alrasbi et al. (2010), reported that date plants have capacity to control ion homeostasis through restricted entry and exit of Na^+, Cl^-, through maintain the K^+ internal cellular content. According to research trials of Alrasbi et al. (2010), Khalas, Khunaizy, and Abunarinjah varieties showed normal growth following irrigation with saline water at 9 dS m^{-1}. However, they observed 50% reduction in growth parameters at 18 dS m^{-1} salinity. The mechanism of salt tolerance was Na and Cl in the leaves through counteracting with K.

Olives

Olive tree has shown promising salt tolerance potential and researchers have pointed out salt exclusion as a major phenomenon behind this story (Gucci and Tattini, 1997). Some varieties showed moderate salinity tolerance while certain others were highly salt tolerant. In the saline environment of Northern Chile, Sotomayer et al. (1990) demonstrated excellent yield following irrigation with saline water (13 dS m^{-1}). The truck growth seemed to have relation with age. A decrease of 30% in 2000 and 55% in 2001 as compared with 1999 was observed; salinity tolerance potential decreased with the passage of time (Aragues et al. 2005). Furthermore, Fernandez and Moreno (1999) demonstrated that olive is sensitive to waterlogging and should be preferentially cultivated in sandy and well-drained soils. Chartzoulakis (2005) showed the salt tolerance in olives depended upon the cultivars and prevention of salt translocation was the main mechanism involved in this context. Meanwhile, osmotic adjustment, stomatal closure, and leaf abscission appeared to play a role. The fruit weight and oil content decreased under salt stress.

Conclusion and future research needs

Selection and potential use of tolerant genotypes with proven adaptation capacity to nutrient poor marginal lands provides good opportunity to achieve stable yield. Crop diversification, innovative high-throughput phenotyping strategies, and sustainable agriculture based on drought and salt-tolerant plant species are likely to be the key factor for maintaining/improving food security in marginal environments. Crop diversification is a very cost-effective option to improve the productivity of marginal lands with high economic return. The joint research strategies could promote the development, improvement, and use of diversified crops such as cereals, oil seed crops, forages, and legumes to shift from subsistence farming to climate smart agriculture. We can conclude that cereals, oil seed crops, forages, and legumes, should have equal importance when crop diversification will be adapted for increasing sustainable agriculture. Different strategies in terms of high throughput technologies, genomic resources, genes associated with stress responses have to be recruited to generate stress tolerant diversified crops. Crops improvement and sustainable production systems need to be integrated in order to address more efficiently future demands of food production presently exacerbated by global climate changes.

In future, the linkages between farmers, researchers, policy makers, and community workers needs to be strengthen in order to achieve the maximum benefits from the use of nonconventional water resources and crop diversification. In this context, it is of primary importance to foster the use of drought and salt tolerant genotypes, agroecological principles, plant biodiversity, and nonconventional water resources to speed up the process of sustainable development on the marginal lands. Farmers and research scientist should have to continue dialogues at different platforms to gain maximum output from crop diversification. Meanwhile, better utilization of agrobiodiversity, environmental resources, and providing climate smart solutions to the farmer's current problems should be on the top of the agenda at the regional and national level. Providing better options to farmers to grow alternate crops will enhance their capacity to adapt to the climate change agriculture perspectives. Inclusion of medicinal and industrial crops (oil seed and lignocellulose crops) in the current cropping system will stabilize the farmer's income in a sustainable way and opportunity to better utilization of available natural resources in a judicial way.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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