Arab Gulf Journal of Scientific Research, 27 (4): 195- 203 (2009)

Research Paper Ref. No 2526

Alternative Crops for Diversifying Production Systems in the Arabian Peninsula

محاصيل بديلة لتنويع الإنتاج الزراعي في شبه الجزيرة العربية

N. K. Rao, Mohammed Shahid and Shabbir A. Shahid

ن.ك. راو، محمد شاهد و شابير أحمد شاهد

International Center for Biosaline Agriculture

P O Box 14660, Dubai, UAE

E-Mail: n.rao@biosaline.org.ae

Abstract: Pilot studies were conducted at the Dubai based International Center for Biosaline Agriculture with the objective to identify alternative crops with potential for diversification of production systems in the Arabian Peninsula. Among the many crops examined, quinoa, cowpea, pigeonpea and mustard showed good adaptation to the environment and produced yields comparable to those reported from highly productive environments. Thus, maximum seed yield recorded was 2.58 t ha^{-1} in quinoa (Ames 13761), 3.09 t ha^{-1} in cowpea (TVu 9725), 3.56 t ha^{-1} in pigeonpea (ICP 995) and 3.04 t ha^{-1} in mustard (ATC 93142). These crops are tolerant to drought and salinity and have a wide range of uses, thus making them promising alternative crops for diversification of production systems and the economic use of marginal land and water resources. The ten best performing accessions were selected in each crop for further evaluation and development of suitable agronomic practices to introduce them to the farmers in the region.

Keywords: *alternative crops, Arabian Peninsula, desert farming, Quinoa, Cowpea, Pigeonpea, Mustard.*

المستخلص: نفذ المركز الدولي للزراعة الملحية في مقره بدبي دراسات إرشادية تهدف إلى تحديد المحاصيل التي تساهم في زيادة التنوع الحيوي لأنظمة الإنتاج الزراعية في شبه الجزيرة العربية. من أفضل هذه المحاصيل الكينوا واللوبيا والبسلة الهندية والخردل التي تأقلمت بشكل جيد مع البيئة المحلية فكانت غلتها مماثلة للغلة في البيئات مرتفعة الإنتاجية. فقد بلغت الإنتاجية العظمى 2.58 طن هكتار-1 في الكينوا (Ames 13761)، 3.09 طن هكتار-1 في اللوبيا (TVu 9725)، 3.56 طن هكتار-1 في البسلة الهندية (ICP 995)، 3.04 طن هكتار-1 في الخردل (ATC 93142). وبما أن هذه المحاصيل تتحمل الجفاف والملوحة بدرجة معتدلة ولها استخدامات كثيرة مما يجعلها كمحاصيل بديلة واعدة لتنويع أنظمة الإنتاج الزراعية والاستخدام الاقتصادي لموارد الأراضي والمياه الهامشية. وقد اختيرت أفضل عشرة سلالات إنتاجية من كل محصول لتنفيذ المزيد من الاختبارات عليها وتطوير الطرق الزراعية الملائمة لإدخالها لاحقاً في حقول المزارعين بالمنطقة.

كلمات مدخلية : *محاصيل بديلة، شبه الجزيرة العربية، الزراعة الصحراوية، الكينوا، اللوبيا، البسلة الهندية، الخردل.*

INTRODUCTION

The Arabian Peninsula is one of the driest regions in the world with very low and unreliable rainfall. It is also one of the hottest regions in the world with day temperatures in summer often exceeding 50°C. The soils of the Arabian Peninsula reflect the aridity of the climate. Most are poorly developed, shallow and rich in lime, gypsum or salts. Due to the hot climate, the percentage of organic substance in the soil is very low (less than 1%) to improve the physical properties and support proper plant growth. The high percentage of calcium carbonate leads to many other problems related to soil fertility, such as increasing soil buffering capacity and fixation of phosphorous and certain micronutrients. As a result, only a limited number of crops grow successfully under these conditions.

The Arabian Peninsula lacks major river systems and many countries within it depend almost entirely on groundwater to irrigate crops. In many countries, an increase in farming areas and large-scale extraction have depleted the groundwater reserves faster than the aquifer recharge from scanty rainfall. Making matters even more difficult, the growing urban areas are taking priority over the scarce freshwater, leaving agriculture to use low-value brackish or salty water that can increase the risk of soil salinization.

Due to the narrow range of crops grown in the Arabian Peninsula, countries mainly depend on food imports. In recent years, food export restrictions by some countries have raised public concerns over food security in the region. These concerns have focused attention on the search for new opportunities through crop diversification. The successful introduction of a new crop, although often a lengthy process, can have a profoundly beneficial effect on the local economy. The International Center for Biosaline Agriculture (ICBA) in Dubai, United Arab Emirates (UAE), has been evaluating the growth and productivity of several field crops proven with or potential salt-tolerance, with the objective of studying their adaptation and yield potential so as to introduce them to the farmers in the Arabian Peninsula countries. The manuscript summarizes the results of pilot studies undertaken to identify new crops that have good potential for diversification of agricultural production systems in the Arabian Peninsula. A wide range of crops, new to the Arabian Peninsula and appearing to have potential for introduction were examined for adaptation and yield potential. These crops, which included quinoa (*Chenopodium quinoa* Willd.), cowpea (*Vigna unguiculata* (L.) Walp), and pigeonpea (*Cajanus cajan* (L.) Millisp.) mustard (*Brassica jumncea* (L.) Czern) among others are discussed in this paper.

Quinoa is an annual herb which produces light yellow to pink seeds in large sorghum-like clusters (Figure1.A-B). Quinoa is thought to have originated in the high mountain plains of the Andes in Peru and Bolivia. The genetic variability of quinoa is reportedly huge, with cultivars adapted to growth from sea level to 4000 m above sea level, from 40°S to 2°N latitude, and from cold, highland climates to subtropical conditions, making it possible to select, adapt, and breed cultivars for a wide range of environmental conditions. The main uses of it are for cooking, baking, etc.; modified food products such as breakfast cereals, pasta, and cookies; and the industrial use of starch. Quinoa seeds are highly nutritious with outstanding protein quality and high amounts of a range of vitamins and minerals (Schlick and Bubenheim, 1996; Jacobsen, 2003; Bhargava, *et al.* 2006). The protein content in grain ranges from 7.5 to 22.1% with an average of 13.8% (Cardozo and Tapia, 1979). Because of its exceptional nutritional quality, quinoa has been selected by the Food and

Fig. 1 (A-B)
A. Quinoa grown under desert conditions in Dubai, UAE
B. Quinoa seed heads

Agriculture Organization (FAO) as one of the crops destined to offer food security in the next century (Jacobsen, 2003). Quinoa can grow with as little as 200 mm of rainfall and in sandy soil. The crop has also demonstrated unusually high salt tolerance with many varieties tolerating salt concentrations as high as 40 dS m^{-1} (Jacobsen, *et al.* 2003).

Cowpea is a highly variable annual legume species that originated in Africa. Besides Africa, it is widely grown in Latin America, Southeast Asia and southern United States, for animal and human consumption. Crude protein levels of cowpea are usually around 23-25%. It is a major source of proteins, minerals and vitamins in the daily diet of the urban and rural poor in Africa and Asia (Davis, *et al.* 1991). Cowpea is moderately tolerant to salinity with a threshold of 4.9 dS m^{-1} (Wests and Francois, 1982; Mass and Poss, 1989; Murillo-Amado, *et al.* 2001, 2006). In addition it is reported to have a good tolerance to heat and drought (Rachie and Roberts, 1974; Turk, *et al.* 1980). Cowpea also has very good forage value (Davis, *et al.* 1991). With the crude protein levels ranging from 16% to 20% and digestibility comparable to alfalfa, it is an excellent fattening feed for livestock (Mullen, *et al.* 2003).

Pigeonpea is a leguminous shrub cultivated in the tropics and subtropics for a wide range of uses such as food, animal feed and fuel. In the Indian subcontinent, dried and split seeds (called dhal) are an important source of protein. In the Caribbean and East Africa, immature pods and green seeds are used as vegetables. Vitamin A and C contents of vegetable pigeonpeas are five times higher than those of green peas (Faris, *et al.* 1987). Therefore, green seeds of pigeonpea can be an ideal substitute for the garden pea. Furthermore, pigeonpea is an excellent forage crop because of its exceptional nutritional value and high productivity. The crude protein values of fresh forage ranging from 14-24% and annual forage yields exceeding 50 t ha^{-1} under intensive management have been reported (Whiteman and Norton, 1981). In addition to its use as a food and feed legume, the pigeonpea has outstanding soil amelioration and conservation properties. The leaves are an important source of organic matter and nitrogen; when allowed to perennialize, pigeonpea can drop as much as 1.6 t ha^{-1} of litter onto the soil in the first year (Sheldrake and Narayanna 1979). Pigeonpea nodulates with a wide range of Rhizobium strains and consistently fixes 20-140 kg ha^{-1} in infertile soils (Anderson, *et al.* 2001).

Mustard, commonly known as Brown or Indian mustard, is a cool season annual vegetable, usually grown for its variable, glabrous, rather thin basal leaves which are eaten raw or cooked like spinach. It is believed to have originated at several different locations with centers of diversity found in China, eastern India and the Caucasus. In India, it is grown more for its seeds which yield an essential oil and condiment. The salt tolerance of *B. juncea* has been reported by many investigators with high salinity thresholds (9-11 dS m^{-1}) (Ashraf and Mcneilly, 1990; Sharma and Gill 1994). Brown mustard has partial drought tolerance between that of wheat and rapeseed. Moisture stress caused by hot, dry conditions during flowering result in lower yields (Oplinger, *et al.* 2001).

MATERIALS AND METHODS

The crops studied for adaptation and yield potential were selected based on the information available in literature on salt-tolerance (Mass and Grattan 1999). The number of accessions studied in each of these crops and the sources from which the seeds were acquired are presented in Table (1). All the crops were grown at the ICBA research station (25°05'49" N and 55°23'25"E) in the years from 2006 to 2008. The soil fertility of the experimental site was improved by incorporating organic fertilizer (compost) at the rate of 40 t ha^{-1}. Sowings were completed in mid-October or early-November by dibbling. Each accession of 3-m was planted in two or three rows each, spaced 50 cm apart. The distance between plants within each row and between two accessions was maintained at 25 cm and 1 m, respectively. The plants were irrigated with low-salinity water of about 3 dS m^{-1} using the drip-irrigation system. Water was applied at the rate of 4L/h for 20 mins each day. A single dose of urea at the rate of 40 kg/ha, one month after planting, and two split doses of NPK (20:20:20) at the rate of 50 kg/ha were applied by banding alongside the rows during crop growth. As a prophylactic treatment, micronutrients were applied (3-4 kg ha^{-1}) as foliar spray twice during crop growth. There were no major problems from pests, except for Aphids when the plants were very young, which was controlled by insecticide spray.

Standard agronomic data such as plant height, days to 50% flowering, seed weight yield and yield components were recorded from five randomly selected plants within each accession. All crops were harvested at full maturity and dried at 25°C under forced ventilation before manual extraction of the seed. The seed yield potential of individual accessions is expressed in t ha^{-1}, which was estimated from the average single plant yield. Based on the relative yield, the ten best-performing accessions were selected within each crop (Table 2) for a more detailed evaluation for saline tolerance and development of suitable production and management systems for possible introduction to the farmers in the region.

RESULTS AND DISCUSSION

The native soil at ICBA is fine sand in texture, non-saline (ECe 1.2 dS/m), moderately alkaline (pH 8.22), strongly calcareous (up to 53% $CaCO_3$), and with very low organic matter (<0.5%). The mean maximum temperatures during the cropping period (October-May) ranged between 26° and 38°C. The minimum temperatures varied between 14° and 24°C. Growth was slow in quinoa, pigeonpea, and cowpea during the first 4-6 weeks after emergence but became luxuriant afterwards. All the crops, except pigeonpea flowered normally and completed their life cycle after the end of the growing season in April-May. The pigeonpea flowering was sparse and all the accessions quickly shifted into a vegetative phase of growth after an initial flush in January-February. With sustained irrigation, growth continued during summer months (June-October), the onset of winter in November was marked by a reduction in the mean temperatures and a shortened day length, which induced profuse flowering and pod formation in all the accessions.

Quinoa

The range of variability in some agronomic characters of the ten best performing quinoa accessions is presented in Table (3). Ames 22157

Table 1. Crops and number of accessions used in the study.

Crop	Taxonomic name	No. of accessions	Source
Quinoa	*Chenopodium quinoa*	121	Regional Plant Introduction Station, Ames, Iowa, USA
Cowpea	*Vigna unguiculata*	23	International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria
Pigeonpea	*Cajanus cajan*	137	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India
Mustard	*Brassica juncea*	100	The Australian Temperate Field Crops Collection, Horsham, Australia

Table 2. The ten best-performing accessions and their seed yield (in parenthesis) in order of superiority.

Crop	Accession number and yield (t ha^{-1})
Quinoa	Ames 13761 (2.58), NSL 106398 (1.94), NSL 106399 (1.49), NSL 86649 (1.43), Ames 13723 (1.34), Ames 22157 (1.33), Ames 13727 (1.33), Ames 13757 (1.20), NSL 106395 (1.19), Ames 13742 (1.18)
Cowpea	TVu 9725 (3.09), TVu 9716 (2.70), TVu 9443 (2.67), TVu 9671 (2.59), TVu 9751 (2.51), TVu 9510 (2.41), TVu 9498 (2.26), TVu 9666 (2.24), TVu 9557 (2.21), TVu 9615 (2.15)
Pigeonpea	ICP 995 (3.56), ICP 8921 (3.08), ICP 14722 (2.99), ICP 14801 (2.87), ICP 9691 (2.64), ICP 7 (2.62), ICP 2698 (2.62), ICP 6668 (2.60), ICP 6049 (2.27), ICP 1273 (2.22)
Mustard	ATC 93142 (3.04), ATC 93358 (2.90), ATC 93337 (2.89), ATC 93402 (2.85), ATC 93384 (2.84), ATC 93161 (2.73), ATC 90783 (2.70), ATC 93162 (2.48), ATC 93204 (2.42), ATC 93563 (2.42)

was the earliest to flower which was 47 days and Ames 13761 was the tallest in height, measuring up to 118 cm at maturity. Seed yield was highest in Ames 13761 (2.58 t ha^{-1}), followed by NSL 106398 (1.94 t ha^{-1}) and NSL 106399 (1.49 t ha^{-1}). Under traditional farming conditions, quinoa yields were reported to vary between 0.4-1.2 t ha^{-1} and with improved management, yields exceeding 2 t ha^{-1} were obtained (Oelke, *et al.* 1992; Schlick and Bubenheim, 1996; Bhargava, *et al.* 2007). In the present study, while seed yields in many accessions were higher than those from traditional growing conditions, accessions such as Ames 13761 and NSL 106398 produced yields comparable to those reported under improved management. The results, in addition to showing that quinoa has good adaptation and can be successfully cultivated in the Arabian Peninsula, demonstrate the importance of cultivar selection for successful introduction.

Cowpea

The pattern of growth was indeterminate in all the ten selected accessions and with sustained irrigation after the seed harvest, many accessions continued vegetative growth and became viney. Table (3) shows the variability in agronomic traits of the ten best cowpea accessions. A bimodal pattern of flowering was observed in all the accessions with the first peak occurring 8-12 days after the 50% flowering and the second peak coinciding with the increase in mean temperatures in April. The 100-seed weight was observed to be maximum in TVu 9443 (18.5 g) and minimum in TVu 9751 (9.4 g). The seed yield, averaged over the ten accessions, was 2.05 t ha^{-1}, with TVu 9725 producing the highest yield (3.09 t ha^{-1}), followed by TVu 9716 (2.70 t ha^{-1}) and TVu 9443 (2.67 t ha^{-1}). In cowpea, global seed yields are reported to range between 1.5 and 2.5 t ha^{-1} (Mullen, *et al.* 2003). In the present studies, yields of several accessions were higher than 2 t ha^{-1}, showing that cowpea has excellent potential as a candidate for crop diversification in the Arabian Peninsula (Figure 2. A- B).

In cowpea, green fodder yields of 22.6 t ha^{-1} and dry matter yields of over 4 t ha^{-1} have been reported (Ibrahim, *et al.* 2006). In our study, although data on forage yield was not recorded, a few accessions such as Tvu 9443, TVu 9751 and

Table 3. Agronomic characters of the top-performing accessions of four crops grown under Dubai (UAE) conditions.

Crop	Plant height (cm)		Days to flower		100-Seed weight (g)		Yield (t h^{-1})	
	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range	Mean±SE
Quinoa	58.3-85.3	85.3±5.42	47-67	54.6±1.87	0.3-0.4	0.3±0.09	1.20-2.58	1.50±0.14
Cowpea	60.6-81.4	69.6±2.25	75-100	88.0±2.20	9.4-18.5	14.6±0.89	2.15-3.09	2.48±0.09
Pigeonpea	200.0-319.3	273.5±12.07	92-134	107.6±3.44	6.2-10.4	8.3±0.43	2.22-3.56	2.75±0.13
Mustard	193.1-253.1	219.1±5.47	51-69	56.3±1.54	0.1-0.3	0.2±0.02	2.42-3.04	2.73±0.07

Fig. 2 (A-B)
A. Cowpea germplasm evaluation for adaptation and yield potential
B. Cowpea in pod formation stage

TVu 9716 produced luxuriant vegetative growth, showing promise for cultivation as a forage crop. Cowpea is also suitable for growing as a summer crop by sowing in late winter (January-February). When grown in summer as a seed crop, vegetative growth and flowering duration were observed to be shorter, resulting in somewhat lower seed yields (except TVu 9716, which produced 3.18 t ha^{-1}), compared to the winter planting (ICBA, 2009).

Pigeonpea

There were considerable variations in the agronomic traits in the ten best performing pigeonpea accessions (see Table 3). Plant height, measured eight months after sowing, was maximum in ICP 8921 (319 cm). While ICP 8921 which was the earliest to flower, within 92 days, ICP 14722 flowered very late, 132 days after sowing. The100-seed weight was greatest (10.4 g) in ICP 14722, followed by ICP 8921 (10.1 g). Seed yield, averaged over ten accessions, was 2.75 t ha^{-1}, with ICP 995, ICP 8921 and ICP 14722 performing best with yields of 3.56, 3.08 and 2.99 t ha^{-1} respectively. The average yields of pigeon pea, reported from a broad range of environments, varied between 0.5 and 2.5 t ha^{-1} but increased to 3 t ha^{-1} in favorable environments (Snapp, *et al.* 2003; Mullen, *et al.* 2003). Thus, yields obtained in this study are comparable to those reported from favorable environments which shows that pigeonpea has good adaptation, and therefore high potential for crop diversification in the Arabian Peninsula (see Figure. 3 A-B).

With reference to saline tolerance, pigeonpea appears to be moderately sensitive, but appreciable genotypic differences were reported, which provides scope for improvement of salt tolerance through mass selection and breeding (Ashraf, 1994). In our study, no adverse effect on growth and yield potential was observed, although the quality of water used for irrigation was low (salinity of about 3 dS m^{-1}). Pigeonpea also has more drought tolerance than many other grain legumes and reportedly maintains vegetative growth during prolonged dry months because of osmotic adjustment and the strong tap root established during the first few months of growth (Anderson, *et al.* 2001). At the ICBA research station, the aboveground fresh biomass of up to 3.15 kg $plant^{-1}$; and dry biomass of 0.99 kg $plant^{-1}$ was recorded, thus demonstrating the high potential of pigeonpea as a new forage crop for the region (ICBA, 2009).

Mustard

The variability in agronomic traits of the ten best performing mustard accessions is shown in Table 3. For plant height, ATC 93337 was the tallest with 253 cm, followed by ATC 93162 (237 cm) and ATC 90783 (228 cm). While ATC 93358 was the earliest to flower in 51 days, ATC 90783 flowered later than others which was specifically 69 days after sowing. The 100-seed weight was observed to be greatest in ATC 93563 (0.34 g), and least in ATC 90783 (0.09 g). Seed yield was highest in ATC 93142 with 3.04 t ha^{-1}, followed by ATC 93358 and ATC 93337 with 2.90 t ha^{-1} and 2.89 t ha^{-1} respectively. In mustard, dryland yields were reported to vary between 900-1200 kg ha^{-1} and favorable growing conditions yielded 2.5 to 3.0 t ha^{-1} (Oplinger, *et al.* 1991). In this study, yields of several accessions were higher than 2 t ha^{-1}, indicative of the excellent adaptation and very high seed yield potential of mustard in the arid production systems of the Arabian Peninsula (Figure. 4 A-B).

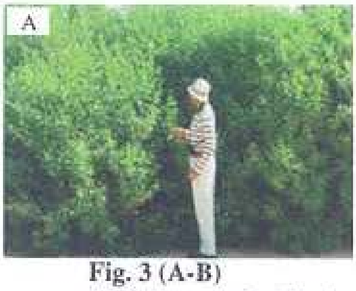

Fig. 3 (A-B)
A. Eight-months old pigeonpea germplasm grow out
B. Profuse podding in pigeonpea

Fig. 4 (A-B)
A. Mustard germplasm evaluation for adaptation and yield potential
B. Prolific fruit (silique) bearing in mustard

There are reports on the potential of canola (*B. napus*) and rapeseed (*B. campestris*; both closely related to mustard) as alternative crops in Saudi Arabia (Al-Jaloud, *et al.* 1996). However, the authors are not aware of any trials with mustard in the region.

CONCLUSIONS

The diversification of production systems through the introduction of new crops not only offer alternative means of sustaining agricultural productivity under adverse conditions, but also increases farm income by diversifying products, improving human and livestock diets, and creating new agro-industries. New crops also serve the strategic interests of the nation by providing domestic sources of materials to reduce import. The candidate crops identified for introduction in the Arabian Peninsula countries should be capable of producing economic yields under harsh growing conditions. In this regard, quinoa, cowpea, pigeonpea and mustard appear to be highly promising candidates for introduction as alternative crops to diversify the production systems. It is pertinent to note that the seed yields reported in this paper were obtained under minimal management and higher yields could be expected though development of improved agronomic practices. Although results reported in this paper are from unreplicated trials, they give sufficient indication of the high potential of the crops for profitable cultivation under desert conditions. Successful development of the new crops and technology transfer for large scale adaptation by the farmers nevertheless require further agronomic research, followed by extensive work to translate the research results into practical recommendations, such as the development of efficient post-harvest technologies and linkages with markets. Making the crops popular would also require effective dissemination of information about the value of crops to the farmers as well as the consumers.

REFERENCES

Al-Jaloud, AA, Hussian, G, Karimulla, S, and **Al-Hamidi, AH** (1996) Effect of irrigation and nitrogen on yield and yield components of two rapeseed cultivars. *Agric. Water Manage.* **30**: 57-68.

Anderson, S, Gundel, S, Pond B, and **Triomphe, B** (2001) *Cover Crops in Smallholder Agriculture: Lessons from Latin America. Intermediate Technology development Group.* (ITDG) Publishing, London, UK.

Ashraf, M (1994) Salt tolerance of pigeonpea (*Cajanus cajan* (L.) Millisp.) at three growth stages. *Ann. Appl. Biol.* **124:** 153-164.

Ashraf, M, and **McNeilly, T** (1990) Responses of four *Brassica* species to sodium chloride. *Environ. Exp. Bot.* **30**: 475–487.

Bhargava, A, Shukla, S, and **Ohri, D** (2006) *Chenopodium quinoa* –an Indian perspective. *Ind. Crop. Prod.* **23:** 73-87.

Bhargava, A, Shukla, S and **Ohri, D** (2007) Genetic variability and interrelationship among various morphological and quality traits in quinoa (*Chenopodium quinoa* Willd.). *Field Crops Res.* **101:** 104-116.

Cardozo, A, and Tapia, ME (1979). Valor Nutritivo. Quinua y Kaniwa. Cultivos Andinos.

In: **Tapia, ME (ed.)** *Serie Libros y Materiales Educativos, vol. 49.* Instituto Interamericano de Ciencias Agricolas, Bogota, Columbia, pp. 149-192.

Davis, DW, Oelke, EA, Oplinger, ES, Doll, JD, Hanson, CV, and **Putnam, DH** (1991) Cowpea. *In: Alternative Field Crop Manual.* University of Wisconsin Cooperative Extension Service, University of Minnesota Extension Service, Center for Alternative Plant & Animal Products. Available at: http://www.hort.purdue.edu/newcrop/afcm/cowpea.html, accessed 6 May 2009.

Faris, DG, Saxena, KB, Mazumdar, S, and **Singh, U** (1987) *Vegetable Pigeonpea: A Promising Crop for India.* ICRISAT, Patancheru, India.

Ibrahim, M, Rafiq, M, Sultan, A, Akram M, and **Goheer, MA** (2006) Green fodder yield and quality evaluation of maize and cowpea sown alone and in combination. *J. Agric. Res.* **41:** 15-21.

ICBA (2009) *Annual Report 2008 (1428-28H).* International center for Biosaline Agriculture, Dubai, United Arab Emirates (unpublished).

H Jacobsen, SE (2003) The worldwide potential for Quinoa (*Chenopodium quinoa* Willd), *Food Rev. Int.* **19:** 167–177.

Jacobsen, SE, Mujica, A, and **Jensen, CR** (2003) The resistance of quinoa (*Chenopodium quinoa* Willd.) to adverse abiotic factors. *Food Rev. Int.* **19:** 99–109.

Mass, EV, and **Grattan, SR** (1999) Crop yields as affected by salinity. *In:* **Skaggs, RW,** and **Van Schilfgaarde, J (eds.)** *Agricultural Drainage.* American Society of Agronomy,. Madison, USA, pp. 615-657.

Mass, EV and **Poss, JA** (1989) Salt sensitivity of cowpea at various growth stages. *Irri. Sci.* **10:** 313–320.

Mullen, CL, Holland, JF, and **Heuke, L** (2003) *AGFACTS: Cowpea, Lablab and Pigeon Pea.* Available at: http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/157488/cowpea-lablab-pigeon-pea.pdf, accessed 6 May 2009.

Murillo-Amador, B, Troyo-Diéguez, E, López-Cortés, A, Jones, HG, Ayala-Chairez, F, and **Tinoco-Ojanguren, CL** (2001) Salt tolerance of cowpea genotypes in the emergence stage. *Aust. J. Exp. Agric.* **41:** 1–8.

Murillo-Amador, B, Troyo-Diéguez, E, García-Hernándezosé, JL, López-Aguilar, R, Ávila-Serrano, NY, Zamora-Salgado, S, ,Rueda-Puente, EO, and Kaya C (2006) Effect of NaCl salinity in the genotypic variation of cowpea (*Vigna unguiculata*) during early vegetative growth. *Sci. Hort.* **108:** 423-431.

Oelke, EA, Putnam, DH, Teynor, TM and **Oplinger, ES** (1992) Quinoa. In: *Alternative Field Crops Manual*, University of Wisconsin Cooperative Extension Service, University of Minnesota Extension Service, Center for Alternative Plant & Animal Products. Available at http://www.hort.purdue.edu/newcrop/afcm/quinoa.html, accessed 6 May 2009.

Oplinger, ES, Oleke, EA, Putman, DH, Lelling, KA, Kaminsid AR, Teynor TM, Doll JD and **Durgan, BR** (1991) Mustard. In: *Alternative Field Crops Manual*, University of Wisconsin Cooperative Extension Service, University of Minnesota Extension Service, Center for Alternative Plant & Animal Products. Available at: http://www.hort.purdue.edu/newcrop/afcm/mustard.html, accessed 6 May 2009.

Rachie, KO, and **Roberts, LM** (1974) Grain legumes of the lowland tropics. *Adv. Agron.* **26:** 62–67.

Schlick, G, and **Bubenheim, DL** (1996) Quinoa: candidate crop for NASA's controlled ecological life support systems. *In:* **Janick, J (ed.)** *Progress in new crops.* ASHS Press, Arlington, VA. pp. 632-640.

Sharma, PC, and **Gill, KS** (1994) Salinity-induced effect on biomass, yield, yield-attributing characters and ionic contents in genotypes of Indian mustard (*Brassica juncea*). *Indian J. Agric. Sci.* **64:** 785-788.

Sheldrake, AR and **Narayananan, A** (1979) Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). *J. Agr. Sci.* **92:** 513-526.

Snapp, SS, Jones, RB, Minja, EM, Rusike, J and **Silim, S** (2003) Pigeonpea for Africa: a versatile vegetable – and more. *HortScience* **38:** 1073-1079.

Turk, KJ, Hall, AE, and **Asbell, CW** (1980) Drought adaptation of cowpea. I. influence of drought on seed yield. *Agron. J.* **72:** 413–420.

Wests DW, and **Francois,** LE (1982) Effects of salinity on germination, growth and yield of cowpea. *Irrig. Sci.* **3**:169–175.

Whiteman, PC, and **Norton, BW** (1981) Alternative uses of pigeonpea. *In: Proceedings of the International Workshop on Pigeonpeas, Vol.I.* ICRISAT,Patancheru,India,pp.365-377.

Ref. No. (2526)
Rec.11/5/2009
In-revised form: 13/10/2009