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RESILIENCE OF SPICES, MEDICINAL AND AROMATIC PLANTS WITH CLIMATE CHANGE INDUCED ABIOTIC STRESSES

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ABSTRACT

Drought, heat, frost, radiation salinity/sodicity, a shortage of nutrients and chemical pollutants are major abiotic stress and their influence will increase worldwide as a result of climate change. Plants are said to be stressed if their growth or reproductive ability is affected. This leads to yield losses and reduced quality. Plants react to stress factors with morphological, physiological and biochemical adaptations designed to increase their resistance to the stress. Some seed spices are adaptive with anticipated climatic change (rising CO_2 level). However, there may a shift towards the northern hemisphere from the southern with rise in temperature. Salinity found beneficial even for lemongrass and Java citronella up to EC 5 dSm^{-1}. German chamomile, vetiver, jamarosa and citronella eucalyptus have wide ranges of salinity tolerance. Some of the aromatic plants are salt includer type salinity tolerant has potential for hyper accumulation of salt resultant helps in reclaiming the saline soil such as palmarosa. Palmarosa, lemongrass, vetiver, jamarosa, citronella, ambrette, chamomile, fennel, dill, lavender, Japanese mint, mint, ocimum, celery, isabgol, senna, periwinkle, liquorices, Lepidium, Salvadora, ashwagandha, Abutilon, Calotropis, datura, and Jojoba are adoptive in saline alkali and sodic soil and water. Fenugreek, cumin, coriander, nigella and rose scented geranium, davana, lavender and geranium are suitable for nutritionally eroded soil and some of them have association with VAM leads to effective utilization of available nutrients and water. Some of the crops are fairly tolerant to moisture stress like dill, ammi, anise, fennel, Cymbopogon species, Ocimum, Eucalyptus, lavender, rose, aloe, Calotropis, Pedelium, Tribulus and Papaver. Some of the crop varieties like coriander (RCr-20, RCr-436, RCr-446, CS-6, Sadhana, Swathi, Sindhu, Co-1, Co-2, Co-3, Co-4 and Azad Dhania-1), cumin (RZ-19, RZ-209 and RZ-223, GC-3 and GC-4), fennel (RF-125, GF-1 and GF-2), fenugreek (RMt-305, CO-2, Rajendra-Kranti, Hisar Suvarna, Hisar Madhavi and Hisar Mukta), Ajwain (RPA-68, Ajmer-AA-1, Ajmer-AA-2 and Lam Sel-1) and dill (Ajmer-AD-2 and Guj. Dill-2) are fairly tolerance to moisture stress. On the other side, Acorus calamus, cardamom, clove, kewada and mentha could withstand under high water table and regular water logging or submerged conditions. Medicinal rice is also an example of this category. Most of the cases abiotic stresses improve the active principles in medicinal plants and essential oil quality of aromatic plants.

Key words: Climate resilience, Spices, Medicinal Plants, Aromatic plants, Abiotic stresses

INTRODUCTION

Plant growth and productivity is adversely affected by nature's wrath in the form of various abiotic and biotic stress factors. Plants are frequently exposed to a plethora of stress conditions such as low/high temperature, salt, drought, flooding, heat, oxidative stress and heavy metal toxicity. Various anthropogenic activities have accentuated the existing stress factors. Heavy metals and salinity have begun to accumulate in the soil and water and may soon reach toxic levels. Plants also face challenges from pathogens including bacteria, fungi, and viruses as well as from herbivores. All these stress factors are a menace for plants and prevent them from reaching their full genetic potential and limit the crop productivity worldwide. Abiotic stress in fact is the principal cause of crop failure world wide, dipping average yields for most major crops by more than 50% (Bray *et al*., 2000). Abiotic stresses cause losses worth hundreds of million dollars each year due to reduction in crop productivity and crop failure. In fact these stresses, threaten the sustainability of agricultural industry. In response to these stress factors various genes are upregulated, which can mitigate the effect of stress and lead to adjustment of the cellular milieu and plant tolerance. In nature, stress does not generally come in isolation and many stresses act hand in hand with each other. In response to these stress signals that cross talk with each other, nature has developed diverse pathways for combating and tolerating them. These pathways act in cooperation to alleviate stress (Mahajan and Tuteja, 2005).

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It is estimated that less than 10% of the world's arable lands may be free of major environmental stresses (Dudal 1976). Tolerance to biotic stresses is very complex at the whole plant and cellular levels (Foolad *et al.,* 2003a, Ashraf and Harris 2004, Munns and Tester, 2008 and Grewal, 2010). This is in part due to the complexity of interactions between stress factors and various molecular, biochemical and physiological phenomena affecting plant growth and development (Zhu, 2002). Currently, there are no economically viable technological means to facilitate crop production under stress conditions. However, development of crop plants tolerant to environmental stresses is considered a promising approach, which may help satisfy growing food demands of the developing and under-developed countries. Development of crop plants with stress tolerance, however, requires, among others, knowledge of the physiological mechanisms and genetic controls of the contributing traits at different plant developmental stages. In the past 2 decades, biotechnology research has provided considerable insights into the mechanism of biotic stress tolerance in plants at the molecular level. High salt stress disrupts homeostasis in water potential and ion distribution, (Hasegawa *et al*., 2000 and Rontein *et al*., 2002). For example, though stress tolerance mechanisms may vary from species to species and at different developmental stages (Hamdia and Shaddad, 1996), Ashraf, 1994, Floolad, 1999, Floolad and lin, 2001 and Jenkins *et al*., 2010), basic cellular responses to a biotic stresses are conserved among most plant species (Zhu, 2001a; b and Zhu, 2002). Furthermore, different abiotic stress factors may provoke osmotic stress, oxidative stress and protein denaturation in plants, which lead to similar cellular adaptive responses such as accumulation of compatible solutes, induction of stress proteins, and acceleration of reactive oxygen species scavenging systems (Zhu, 2002). Water stress induced leaf abscission is one of the most important drought resistance mechanisms that plants have developed during evolution (Hamdia, 2008, Chalk and Alves, 2010 Hamdia and Shaddad, 2010). Still there is a great scope for the utilization of abiotic stress as an accelerator of yield and quality of spices, medicinal and aromatic plants (MAPs) as most of these are adoptive to the stress environment (Aishwath *et al*., 2010a & b).

STRESS AND ABIOTIC STRESS

Stress in physical terms is defined as mechanical force per unit area applied to an object. In response to the applied stress, an object undergoes a change in the dimension, which is also known as strain. As plants are sessile, it is tough to measure the exact force exerted by stresses and therefore in biological terms it is difficult to define stress. A biological condition, which may be stress for one plant may be optimum for another plant. The most practical definition of a biological stress is an adverse force or a condition, which inhibits the normal functioning and well being of a biological system such as plants (Jones and Jones, 1989). Abiotic stress could be defined as the negative impact of non-living factors on the living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of variation to adversely affect the population performance or individual physiology of the organism at a significant level. These abiotic stresses are –

1. Temperature (low/high).
2. Salinity (salt/alkalinity),
3. Moisture (Drought- water deficit condition and Excess water-flooding),
4. Radiations (high intensity of ultra-violet and visible light),
5. Chemicals and pollutants (heavy metals, pesticides and aerosols),
6. Oxidative stress (reactive oxygen species, ozone and UV radiation)
7. Wind (sand and dust particles in wind) and
8. Nutrient deprivation in soil.

Adaptability and detrimental effect of climate change induced abiotic stresses are described here.

Resilience of Spices, Medicinal and Aromatic Plants with Abiotic Stress

1. Temperature (high/low)

The rising CO2 and other green house gasses (GHGs) in the atmosphere leads to rise earth surface temperature as these are radiative forcing gasses and absorb heat in their vibrating bonds from the sunlight. There are also chances of lower temperature to be occurred in some pockets as an extreme event. In 2008, frost has occurred as an extreme event in Rajasthan and there was severe loss of crops including seed spices and kali-jeeri (Centeratherum antihelmenthese) was completely wiped out from the field. Though most of the seed spices are adaptive to low temperature yet sudden rise and fall in temperature leads to crystallization of apoplastic water resultant loss of cell membrane integrity and ultimately death of cell. The life cycles of plants correspond to seasonal cues, so shifts in the timing of such cycles provide some of the most compelling evidence that global climate change is affecting species and ecosystems (Cleland *et al.,* 2007 and Walther *et al.*, 2002). Available evidence indicates that spring emergence has generally been occurring progressively earlier since the 1960s (Walther, *et al.*, 2002). Such accelerated spring onset has generated noticeable changes in the phenolgical events of many plant species, such as the timing of plant's bud bursts, first leafings, first flowerings, first seed or fruit dispersal, etc. Records indicate that many plants including spices and MAPs have started blooming earlier in response to the earlier occurrences of spring temperatures and weather. A 2003 meta-analysis of 9 phenological studies from various countries, involving 172 plant and animal species, found a mean shift toward earlier spring timing of 2.3 days per decade (Parmesan and Yohe, 2003). Many studies have shown that plant species that normally flower in early spring are experiencing some of the greatest acceleration from warming, whereas species active later in the growing season can be unresponsive or experience delayed phenological events (Cleland *et al.,* 2007). Plants in the wild appear to be more disposed toward phenological shifts than cultivated plants. The accelerated flowering times experienced in medicinal and aromatic plants like- wormwood (*Artemisia absinthium*), feverfew (*Tanacetum parthenium*), and cranberry (*Vaccinium macrocarpon*). St. John's wort (*Hypericum perforatum*)-now flowers 6 days earlier than in Thoreau's day, and peppermint (*Mentha piperita*) now blooms 10 days earlier. Other plants like hawthorn (*Crataegus monogyna* and *C. laevigata*) and horse chestnut (*Aesculus hippocastanum*,) and bloodroot (*Sanguinaria canadensis*,) are also blooming earlier. Highbush blueberry (*V. corymbosum*), for instance, is flowering 2 to 3 weeks earlier in the Concord area than it did in the mid-19th century, whereas many other plants have not demonstrated any change at all. There is an abrupt transition from winter to summer with temperatures in April and May that are more typical for summer temperatures. This has caused, for example, that throughout Europe spring planting of chamomile (*Matricaria recutita*) has been disastrous with an average loss of yield of 80% (Cavaliere, 2009).

Rising temperature (climate changes) also causing plants to migrate into new ranges. Studies and computer modeling programs have found that plant's ranges have begun to shift towards the poles and/or to higher elevations in an effort to reclaim appropriate growing zones (Walther *et al.*, 2002 and Parmesan and Yohe, 2003). The range of economically useful saw palmetto (*Serenoa repens*) plants appears to be slowly shifting northward due to warming temperatures and changing rain patterns. Saw palmetto grows only in the Southeastern United States-primarily in Florida but also in southern areas of Georgia, Alabama, and South Carolina. In some of the northern areas of the plant's range, saw palmetto is able to grow but does not produce a significant amount of berries. Over the last 2 years, it has been noticed that wild saw palmetto berries seem to be more dominant in central Florida than southern Florida, although this has not been confirmed by any published reports of saw palmetto populations. It has been predicted that more berry-producing plants may eventually spread farther into Georgia (where the plants currently grow but do not typically bear fruit. *Stellaria media* (chick weed) or *Salix alba* white willow have great range loss in the east of Germany. It is hypothesized that drier conditions and higher temperatures (in combination) lead to local extinctions of species (Cavaliere, 2009). A rise in a temperature of above 1ºC will have shifted a major area of potential suitable zones. Studies conducted at Indian Institute of Spices Research, Calicut, India using GIS models have shown that many suitable areas of spices will become marginally suitable or new areas, which are presently unsuitable, become highly suitable for cultivation of spices.

2. Salinity and Alkalinity stresses

About 6.73 million ha soils are saline and alkaline out of which 3.77 million ha is alkali/sodic in India. Due to poor physical properties, excessive exchangeable sodium and high pH, most of these lands support a very poor vegetation cover. Theses problem will further rise with changing climate scenario and those could be utilized by seed spices (Aishwath *et al*., 2010b) medicinal and aromatic plants (Aishwath and Nibauria, 2009).

i) Soil salinity:

Dill can be grown up to EC 3.3 dSm^{-1} (Sharma *et al*., 2001). In another study on dill with salinity shows that it comes up well with EC 4-5 dSm^{-1} (Rao *et al.,* 2001 and Singh *et al*., 1995). The beneficial effect of salinity on lemongrass (*Cymbopogon citrates*) and Java citronella (*Cymbopogon winterianus*) was observed at EC 5 dSm^{-1} as compared to lower or its higher levels of salinity (Patra and Singh 1995, Pal *et al.,* 1989). Lemon grass is a very hardy crop which grows successfully on cultivable waste land and the salt affected soil having EC up to 11dSm^{-1}. German chamomile (*Matricaria chamimilla*) can withstand up to salinity 12.0dSm^{-1} without leaving any adverse effects on yield. However, the salinity up to 5.5dSm^{-1} found beneficial with respect to its productivity. Based on the pot culture study, there was no adverse effect on yield and quality of palmarosa observed upto EC 11.5 and beyond that soil salinity may adversely affect the yield and quality of palmarosa.

Figure1: Adaptability of aromatic crops with soil salinity and alkalinity

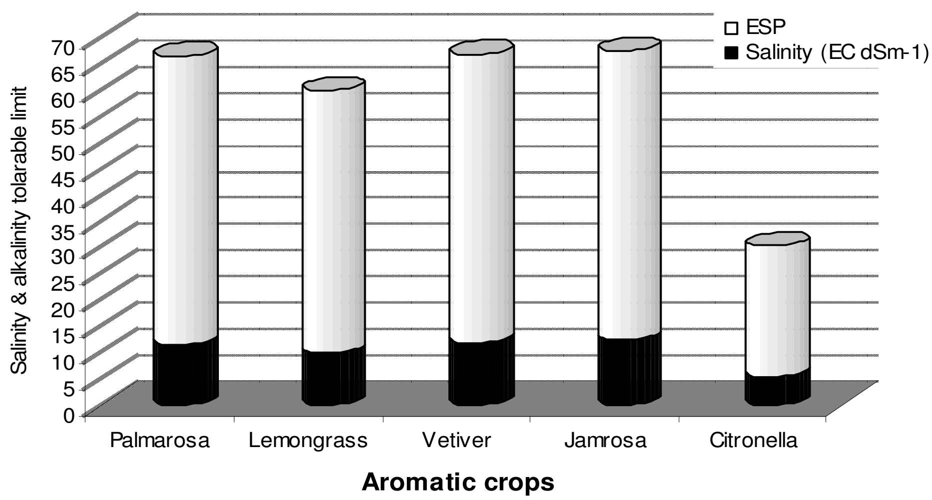
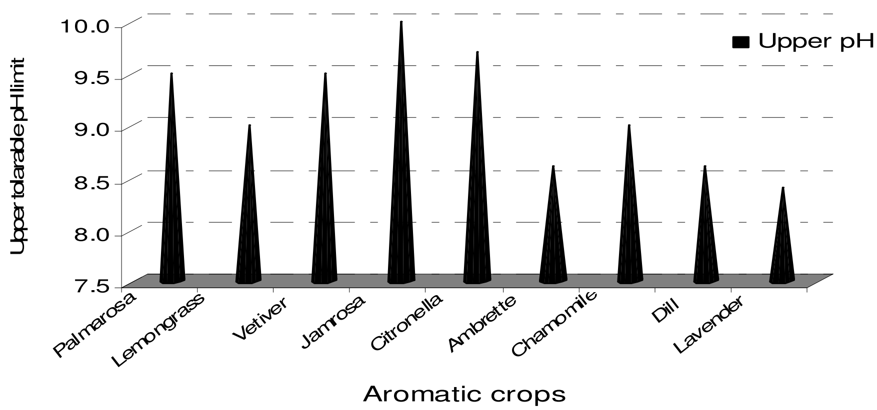


Fig. 1 enunciates that vetiver, jamarosa and citronella could withstand up to salinity 12, 12.5 and 5.5 EC dSm^{-1}, respectively (Singh and Anwar, 1985, Patra and Singh, 1995). In aromatic trees, various species of eucalyptus have wide range of salinity tolerance ie 3.0 to 20.0 EC dSm^{-1} as reported by Gupta and Gupta (1997). Some of the aromatic plants are salt includer type salinity tolerant has potential for hyper accumulation of salt resultant helps in reclaiming the saline soil such as palmarosa and isabgol are the hyper salt accumulator (Aishwath and Pal, 2004, and Aishwath, 2009). Palmarosa grown on the soil having EC 4.8 dSm^{-1}, after two years of cropping, the EC of the soil reduced down to 0.64 dSm^{-1} (Prasad and Singh, 1998). Isabgol can thrive well even up to the salinity EC 10.0 dSm^{-1} with reduced yield. Dagar, (2008) enlisted the following medicinal and aromatic plants, which could withstand under saline soil and water conditions are - *Aegle mamelos* (beal), *Aloe bardabensis*, *Anethum graveolens*, *Azadirachta indica* (neem), *Capparis deciduas* (Kair/kurrel), *Cassia senna* (senna), *Catharanthus reseus* (periwinkle, sadabahar), *Cymbopagon fiexuosus*, *C. martini* (Palmarosa), *Emblica officinalis* (Gooseberry/Aonla), *Euphorbia antisyphalitica*, *Glycyrrhiza glabra* (Liquroce/mulhatti), *Jatropha curcas* (Purging nut/Jamlaghota), *Lepidium sativum*, *Matricaria chamomilla* (German chamomile, babuna), *Ocimum sanctum* (Tulsi), *Plantago ovata* (Psyllium/isabgol), *Ricinus communis* (Castor/arind), *Salvadora persica* (Jaal), *Simmondsia chninsis* (Jojaba/hohoba), *Vetiveria zizanioides* (Vetiver). Ashwagandha (*Withania somnifera*) could come up well in mild saline black soil (Aishwath, 2004).

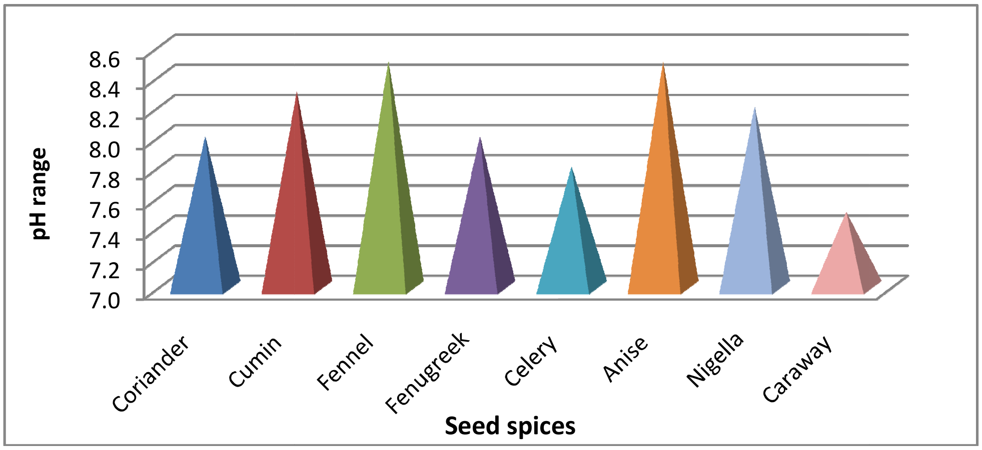
Figure 2: Upper tolerable limit of soil pH for spices, medicinal and aromatic crops



ii) Soil sodicity/alkalinity:

Fennel performs well on heavy textured soils and can also be cultivated on salt affected black soil with salinity of 8-10 dSm^{-1} (Singh, 1999). Fennel and coriander grown on partially reclaimed sodic soil having Exchangeable Sodium Per cent (ESP) 20 with various N and P levels yielded well and large accumulation of Na in fennel stover indicating its tolerance to sodicity. Reduction in soil pH and ESP and increase in exchangeable calcium indicates its capability for reclaiming sodic soils (Garg *et al.*, 2000). Dill (*Anethem graveolens*) can tolerate the pH up to 8.6 (Farooqi, and Sreeramu, 2001). It has been reported that aromatic grasses such as, palmarosa (*Cymbopogon martinii*) and lemongrass (*C. flexuosus*) could successfully be grown on moderately alkali soils having pH up to 9.0 and 9.5, respectively, while vetiver (*Vetiveria zizanioides* L. Nash) which withstands to both high pH and stagnation of water, could successfully be grown without significant yield reduction on highly alkali soils (Fig. 1 and 2). In some cases the yield and quality of vetiver was better on sodic soil (Patra and Singh, 1995, Gupta and Gulati, 1965 and Farooqi and Sreeramu, 2001). These grasses not only produce essential oils used for industrial purpose but also ameliorate the soil (Dagar *et al.* 2004). Palmarosa, lemongrass and vetiver grown for two years on sodic soils having pH 10.6, 9.8 and 10.5, respectively, the reduction in pH was noticed as 9.4, 8.95 and 9.50 in each soil, respectively (Prasad and Singh, 1998, Patra *et al.*, 2002 and Anwar *et al.*, 1996). Japanese mint (*Mentha arvensis*) also comes up well in slightly alkaline soil than acid sedentary soil (Prasad and Chattopadhyay 1999). Among the aromatic grasses like palmarosa, lemongrass, vetiver, citronella and jamrosa, the jamrosa is a high pH (10.0) tolerant and citronella is least (pH 8.5). However, under well supplied organic matter conditions (Fig. 2), even pH up to 9.7 has no detrimental effect on growth, yield and oil content in citronella plant as reported by Gupta and Gulati (1965). In case of amrette (*Abelmoschus moschata*), chamomile (*Matricaria chamomilla*), and Lavender (*Lavandula species*) can tolerate upper pH level as 8.6, 9.0 and 8.4, respectively (Farooqi and Sreeramu, 2001). An another study it was found that dill could be grown up to soil pH 8.8 with slightly yield reduction (Sharma *et al.* 2001). German chamomile can produce 2.5-3.0 t ha^{-1} of flower yield in alkaline soil having pH 9.5 and also have the high sodium uptake efficiency could help in improvement of sodic soil (Patra and Singh, 1995). Seed spices like fennel, cumin and anise are fairly tolerant to higher pH as depected in Fig. 3 (Aishwath and Anwer, 2010b). In general, isabgol can thrive even up to the pH10.0 with reduced yield. However, some of the genotypes perform well with higher alkalinity ranging from 2.0 – 9.2 pH and genotype MIB-153 yielded (1461 kg ha^{-1}) highest among the 9 cultivars. Similarly, CSLT-13 cultivar gave highest oil yield among the 6 cultivars of sweet basil. Data across different locations and sodicity conditions revealed that the best performance was CSS1 genotype and gave about 9 q ha^{-1} seed yield than all other tested lines of dill (Gautam and Nayak, 2008).

Figure 3: Adaptability of seed spices crops with various pH ranges



iii) Salinity and alkalinity of irrigation water

Underground water always contains some soluble salts. Continuous use of such water may leave some harmful affect the crop growth and soil properties depending upon the quality and quantity of salts present. Accumulation of salt in soil profile depends upon the texture, structure and the depth of the soil (Kelly, 1963 and Aishwath and Pal, 2004), which directly affects the yield and composition of the crops (Aishwath and Pal, 2000). The major constraints of underground water uses for irrigation are (i) Salinity and (ii) Sodicity.

Fennel can be cultivated profitably in the salt affected black soils by using saline water of 4 dS m^{-1}. It is also revealed that the water of sub-marginal quality with salinity of 4 dS m^{-1} can be used without any significant yield reduction in dill and it can tolerate a pH of 8.6 (Rao *et al.*, 2001). Usage of saline irrigation water (ECiw 8-10 dS m^{-1}) on highly calcareous saline soils, *Eucalyptus tereticornis* and aromatic grass species vetiver (*Vetiveria zizanoides*) showed great promise by yielding 1.19 to 1.73 t ha^{-1} root biomass. Lemon grass (*Cymbopogon flexuosus*), palmarosa (*Cymbopogon martinii*), ocimum (*Ocimum sanctum*), celery (*Apium graveolens*), mint (*Mentha piperita*), and fenugreek (*Trigonella foenum-graecum*) were irrigated either with saline or canal water alone or with the alteration of canal and saline water. These species have tremendous potential for cultivation with irrigation of underground saline waters having salinity up to 10 dS m^{-1}. Among the aromatic grasses, vetiver was found the most promising, followed by palmarosa and lemongrass (Dagar, 2007). Irrigation water having EC 10.0 and EC 16.0 dSm^{-1} does not have adverse effect on herb, essential oil yield and quality of lemongrass and palmarosa, respectively (Patra *et al.*, 1992). German chamomile is also tolerant to irrigation water salinity up to 8.0 dSm^{-1} and decreased the yield beyond that level of salinity (Patra and Singh, 1995). In *Cymbopogon martinii* the detrimental effect of 4 EC dSm^{-1} was not observed in sandy soil, while same EC level was detrimental for palmarasa on sandy clay loam and sandy loam soils (Aishwath *et al.*, 1990 and Aishwath and Pal, 2004). The irrigation water applied in sandy loam and sandy clay loam soil having SAR 9.1 leaves adverse effect on the yield of palmarosa without any effect on oil content. However, at same level of SAR no adverse effect observed on yield of palmarosa in sandy soil (Aishwath and Pal, 2004). Up to seven numbers of irrigations with sodic (RSC 10.0) water, there was no adverse effect on growth and yield of ambrette, palmarosa, lemongrass and ashwagandha. At the initial stage of establishment of *Pandanus odoratissimus* and *Murraya paniculata* have problem with this sodic water, but after 3-4 years of its establishment no adverse effect on growth was observed with sodic water (Aishwath, 2005a). However, some of the aromatic plant like ginger, lemongrass and jasmine are sensitive for sodic water (Aishwath, 2005b). The adverse effect of high SAR (10.0) of irrigation water did not appear on growth and yield palmarosa. However beyond that level the growth, yield and uptake of the N, P, K, Ca and Mg reduced (Pal *et al.*, 1993).

3. Moisture (a Drought - water deficit condition, b. Excess water-flooding),

3a. Drought (water deficit condition)

Climate change is expected to increase the severity of drought, especially in western India where five river basins are expected to face acute to severe water shortages impacting a large area of Rajasthan and Gujarat. Land uses, cropping patterns and poor water resource management in the twentieth century have resulted in a 50 per cent reduction in the surface water discharge of the Ganga over the last 25 years and in a sharp drop in groundwater tables across the entire Indo–Gangetic plain (Kumar, *et al.*, 2005) . The Ganga, Narmada, Krishna and Kaveri rivers are expected to experience seasonal or regular water stress, impacting western, northern and eastern India (Gosain, *et al.,* 2006). The political and economic consequences of the Kaveri dispute and the Narmada struggles are an indication (Murty, 2002). Indian continent could be severely challenged by these changes and further expected to increase drought in semi-arid peninsular and western India.

Table 1: Improved varieties suitable for rainfed and limited water availability

Crop	Variety	Yield (q ha^{-1})	Duration (Days)	Recommended state / region
Coriander				
	RCr-20	10.0	100-110	Rajasthan
	RCr-436	11.0	90-100	Rajasthan
	RCr-446	12.0	125-130	Rajasthan
	CS-6	8.9	100	Andhra Pradesh
	Sadhana	10.2	95-110	Andhra Pradesh
	Swathi	8.6	80-85	Rainfed areas in Andhra Pradesh
	Sindhu	10.0	100-110	Andhra Pradesh
	Co-1	5.0	110	Tamil Nadu
	Co-2	6.3	90-100	Tamil Nadu
	Co-3	6.5	90	Tamil Nadu, Gujarat and Andhra Pradesh
	Co(CR)-4	6.0	65-70	Tamil Nadu
	Azad Dhania-1	10.0	120-125	Uttar Pradesh
Cumin				
	RZ-19	5.6	130	Rajasthan and Gujarat
	RZ-209	6.5	130-140	Rajasthan
	RZ-223	6.0	120-130	Rajasthan
	GC-3	7.0	100	Gujarat and Rajasthan
	GC-4	12.5	NA	NA
Fennel				
	RF-125	17.3	110-130	Rajasthan
	GF-1	17.2	225	Gujarat
	GF-2	19.4	NA	North Gujarat and Sourashtra region of Gujarat
Fenugreek				
	RMt-305	13.0	120-125	Rajasthan
	CO-2	4.8	85-90	Tamil Nadu
	Rajendra-Kranti	12.5	65-90	Bihar
	Hisar Suvarna	16.0	130-140	Haryana and Rajasthan
	Hisar Madhavi	19.0	130-140	Haryana and Rajasthan
	Hisar Mukta	20.0	135-140	Haryana
Ajowan				
	RPA-68	9.0	140-150	Rajasthan
	Ajmer -AA-1	14.2	160	Rajasthan
	Ajmer -AA-2	12.8	147	Rajasthan
	Lamsel-1	10.0	140	Andhra Pradesh
Dill				
	Ajmer-AD-2	8.0	132	Entire dill areas of Rajasthan
	Guj. Dill-2	9.4	NA	Suitable for rain-fed conditions and heavy black soils of Gujarat

NA= Not available (Source: Johny and Ravindran, 2005)

Vegetation in the dry zones is very sparse. The general landscape is desolate and barren. Herbs appear only during a short period of the year when the conditions become favorable. The herbs, shrubs and trees have various means of storing water. These adaptations include increased ability to store water in their succulent stems or leaves; thickening of the leaf cuticle or reduction of leaf surface or the entire absence of leaves to lower the transpiration rate, and the ability to survive as a seed through many years of aridity. Seed spices are arid and semi-arid crops and come up with limited water conditions, while dill, ammi, anise, fennel, papaver crops are fairly tolerant to moisture stress among the seed spices. Besides that, some of the varieties of seed spices are very promising under drought conditions (Table 1). Medicianl and aromatic plants recommended for arid areas are ferula, artemisia, sage, lemongrass, guggal and Myrrh. Recent research on *Ammi visnaga* and *A. majus*, *Pimpinella anisum, Foeniculum vulgare, Ferula asafetida*, *F. foetida* and *Artemisia* proved to be adaptive in dry areas. Some artemisias are of medicinal interest and a few are prized for their volatile oils. The chief source of santonin, in the USSR, is *A. cine* Berg, growing in abundance in Russian Turkestan and Persia. Other species which have been found to contain santonin include *A. mexicana* Willd., *A. neo – mexicana* Woot, and *A. wrightii*. *A. grey*, found in America and *A. gallica* Willd. in East Germany, France, England and Scotland, and *A. maritime* L., a fairly widely distributed species spread from England to as far as east of China and Mongolia are tolerant to moisture stress. The content of santonin in the American and English species is too low to warrant commercial extraction. *A. fragrans* Willd. and *A. parviflora* Roxb occurring in dry areas of Afghanistan have also been reported to contain santonin. *A. maritime* growing in certain dry areas of Kashmir (India) and Kurram (Pakistan) has been found to contain substantial amounts of santonin (1-2 per cent), which is commercially extracted for aromatic and medicinal purpose. Lemongrass or Indian Verbena (*Cymbopogon citrates, C. schoenanthus* and C. *nardus*) southern parts of the eastern Egyptian desert and which yields a volatile oil are adaptive to water stress. Myrrh is still used to some extent in pharmacology as an aromatic stimulant and fenugreek (*Trigonella foenumgraecum* L.) contains diosgenin content could serve for the demi-synthesis of cortisone derivatives and sex hormones are come up well under water stress (Chopra *et al*., 2003). *Commiphora wightii*, *Cassia angustifolia*, *Withania somnifera*, *Aloe barbadensis*, *Pedalium murex*, *Boerhaavia diffusa*, *Cyperus rotundus*, *Tinospora cordifoila*, *Tribulus terrestris*, *Peganum harmala*, *Calotropis procera*, *Capparis deciduas*, *Andrographis paniculata*, *Catharanthus roseaus*, *Solanum khassianum*, *Cymbopogon fiexousus*, *Cymbopogon martinii*, *Ocimun basilicum*, *Bixa orallena*, *Indigofera tinctoria*, *Lawsonia innermis* etc are come up well under moisture stress conditions (Singh and Samra 2006). There has been work initiated for addressing abiotic stresses in agriculture through transgenic technology-Medicago sativa leaves used for treating poor digestion, cooling poultice and seeds for boils and treating arthritis: the gene *mn-sod* (Mn-Superoxide dismutase protein) taken from *N. plumbaginifolia to* dismute of reactive oxygen intermediates in mitochondria for reduced injury from water deficit stress and increased winter survival for salinity gene *alfin1*(Member of Zn finger family of proteins) was used in alfalfa (Grover, *et al*., 2003).

Table 2: Nutrient removal by some spices, medicinal and aromatic crops

Crop	N uptake (kg ha^{-1})	P uptake (kg ha^{-1})	K uptake (kg ha^{-1})
Menthol mint	109	28	129
Citronella	181	33	255
Lemongrass	160	32	194
Palmarosa	430	62	339
Geranium	180	24	137
Coriander	30	4	36
Davana	179	26	171
Japanese mint	109	28	129
Peppermint	42	--	--

Source: Prakasa rao, 1992 and 1993

3b. Excess water (Flooding)

There has been no accurate estimate of the area afflicted in India under water logging. Framji (1974) reported that nearly 3.5 million hectares area became waterlogged with the rise in water table in the root zone. Recently, Sehgal *et al.* (1998) reported about 20 million hectares area is under flooding causes water logging. According to CWC, 1997 the area under flood and water logging is about 36 Mha. This will further aggravate with changing climate scenario is expected.

Most of the seed spices are susceptible for the water logging condition. However, water logging or submerged conditions can be utilized for the production of *Acorus calamus*, while, cardamom (*Elettaria cardamomum*) is best suited in swampy areas for its ideal production. Clove can withstand for a shorter period under water logging conditions. In case of kewada (*Pandanus species*), it is highly tolerable to water logging conditions for a longer period. The mint species *Mentha arvensis* is moderately tolerable to water logging for 8-10 dyas provided low atmospheric temperature. However, vetiver is capable of prolong water stagnation and also yielded with full potential (Shiva *et al.,* 2002). *Vetiveria zizanoides*, *Terminalia arjuna*, kangkong (*Ipomea aquatica*), bulrush (*Cyperus* spp.), lotus (*Nelumbo nucifera*), water lily (*Nymphaea* spp.) are well adoptive to submerge conditions. Besides the nutritive value of rice, it is used against pimple, boils, headache, epilepsy, Rheumatism, paralysis, skin disease, skin infection and cough. Some of the varieties used as medicinal are - *Aalcha, Baissor, Gathuwanor, Karhani, Kalimoonch, Maharaji, Bhajari, Dhanwar, Orissa Mehar, Saraiphol, Karnataka Kari bhatta, Karikagga, Atikaya, Mullarya, Kerala Nivara, Erumakkari, Himachal Pradesh Katheri*. These crop varieties are for submergence conditions (Amudha *et al*., 2011).

Table 3: Per cent colonization of VAM fungi in spices, medicinal and aromatic plants

Crop	Per cent colonization	Crop	Per cent colonization
Basil	63	*Mentha arvensis*	46
Citronella	75-91	*Mentha piperita*	100
Coriander	32	*Mentha spicata*	100
Cymbopogon citratus	80	*Mentha citrata*	40
Cymbopogon flexuosus	72	Musk	83
Cymbopogon jwarancusa	50	Palmarosa	41-98
Cymbopogon khasianus	76	Patchouli	43
Davana	86	Rose-scented geranium	22-59
Fenugreek	92	Sacred basil	77
Lavender	80	Vanilla	57
Lemongrass	21-75	Vetiver	42

(Aishwath and Tarafdar, 2007)

4. Radiations (high intensity of ultra-violet and visible light)

Plants, due to their sedentary life style, are constantly exposed to environmental stresses, such as wounding, pathogen attack, dehydration and ultraviolet radiation (UV). Plants must be exposed to sunlight for photosynthesis. This implies that they need, by definition, to efficiently deal with the damaging effect of UV radiation. UV radiation damages cellular components, such as membranes, proteins and also DNA (i.e. it forms DNA–protein and DNA–DNA crosslink's (Britt, 1999). In order to minimize the effect of UV radiation plants activate different physiological responses, such as UV sunscreen biosynthetic pathways, reactive oxygen species (ROS) scavenging and DNA repair (Jansen, *et al*., 1998). Upon exposure to UV, photoproducts, such as cyclobutane pyrimidine and pyrimidine (6–4) pyrimidinone dimers, are produced, that are known to be strongly mutagenic (Britt, 1999). Plants do not have a predetermined germ line and form their reproductive organ only in later stages of development. Therefore, sequence alterations that occur in somatic cells can be transmitted through the germ line and passed on to the next generation. DNA repair pathways, such as direct repair (photo reactivation), base excision repair, nucleotide excision repair (NER), mismatch repair and double strand break repair need to be activated upon exposure to DNA damaging agents (Britt, 1999 and Vonarx, *et al*., 1998). UV damage can be directly repaired by photolyases, avoiding an excision process (Britt, 1999). In the absence of light, on the other hand, UV lesions can be repaired by excision of the damaged nucleotides using the NER pathway (Britt, 1999). This process involves damage recognition, chromatin remodeling, damage excision, repair synthesis and chromatin reconstruction (Ura and Hayes, 2002). In Arabidopsis *CENTRIN2* and *SNM1* genes involved in the NER and in recombinational DNA repair of oxidatively induced DNA damage, respectively (Molinier, *et al*., 2005). The growth yield and active principal in medicinal plants and essential oil content in aromatic plant increased while exposed to UV-radiation are *Calotropis sps*, *Glycyrrhiza uralensis, Datura stramonium, Arabidopsis thaliana,* clover (*Trifolium sps*), *Solanum glaucophyllum*, *Nasturtium officinale, Sinapis alba, Tanacetum parthenium, Mentha spicata, Aquilegia caerulea, Fritillaria thunbergii, Camptotheca acuminate, Psychotria brachyceras, Catharanthus roseus, Carthamus tinctorius, Coleus blumei, Rosmarinus officinalis, Petroselinum crispum, Acorus calamus, Thymus vulgaris*, *Majorana hortensis* and *Ocimum basilicum* (Zhang and Björn, 2009).

5. Chemicals and pollutants (heavy metals, pesticides, and aerosols).

Heavy-metal contamination is one of the world's major environmental problems, posing significant risks to agro-ecosystems. Increasing emissions of heavy metals are dangerous because they may get into the food chain with risks for human health (Lantzy and Mackenzie, 1979, Galloway *et al*., 1982, Angelone and Bini, 1992). For the re-cultivation of degraded soils and the reclamation of industrial sites, stress-tolerant plants are required. Biotechnological efforts are underway to improve plant stress tolerance and the ability to extract pollutants from the soil with the aim of using plants for soil clean-up (Salt *et al*., 1995). Conventional technologies for metal-contaminated soil remediation have often been expensive and disruptive. Novel, environmentally friendly and inexpensive solutions are phyto-remediation of heavy metal and hydrocarbon contaminated soils. An unprecedented and rapid change in environmental conditions heavy metal contamination leads to further adverse effect on common field crops. However, some of the seed spices and aromatic plant can be taken successfully without affecting the quality of essential oil of the crops. Since these metals do not interfere directly with cellular oxygen metabolism, the question arises as to the reasons of the observed oxidative stress. To understand the mechanism for exposure to heavy metals also provoked pronounced responses of antioxidative systems, but the direction of the response was dependent on the plant species and tissue analysed. However, some common reaction patterns can be found. In most cases, exposure to heavy metals (Cd) initially resulted in a severe depletion of GSH (Glutathione) in *Rauvolfia serpentina* (Grill *et al*., 1987) and in pine (Schützendübel *et al*., 2001). Spices and aromatic crops can provide economic return and metal-free final product and essential oil in metal contaminated soil. The study in Bulgaria using coriander, sage, dill, basil, hyssop, lemon balm, and chamomile grown at various distances from the smelter revealed that aromatic crops may not have significant phytoremediation potential, but growth of these crops in metal contaminated agricultural soils is a feasible alternative. Herbage essential oil yields of basil, chamomile, dill, and sage were reduced when they were grown closer to the contaminants. Metal removal takes place from the site with the harvestable plant parts was as high as 180 g ha^{-1} for Cd, 660 g ha^{-1} for Pb, 180 g ha^{-1} for Cu, 350 g ha^{-1} for Mn, and 205 g ha^{-1} for Zn. It also reported that high concentrations of heavy metals in soil or growth medium did not result in metal transfer into the essential oil. Of the tested metals, only Cu at high concentrations may reduce oil content (Valtcho *et al*., 2008). No detectable amount of Cd, Cu, or Pb was found in the oils plant species peppermint, basil, and dill. These can be grown in soils enriched with Cd, Pb, and Cu medium without risk for metal transfer into the oils, and without significant alteration of essential oil composition that may impair marketability (Valtcho *et al*., 2006). Zheljazkov and Jekov (1995) investigated by Furnace Atomic Absorption (GFAA) and Inductively Plasma (ICP) techniques. The content of Cd, Pb, Cu, Mn, Zn and other trace elements determined in essential oils and plant extracts from the genera *Rosa*, *Lavandula*, *Mentha*, *Salvia*, *Ocimum*, *Foeniculum*, *Coriandrum*, *Anethum*, *Hyssopus* and *Rhus*. On the other hand the heavy metal content in oils from different regions were compared to heavy metal content in some oils obtained from species grown on heavily polluted soils and under severe atmospheric pollution. They found that the concentration of the most hazardous heavy metals in all of the tested oils and plant extracts was very low, near the detection limits of the used apparatuses. Therefore, most of the essential oil and medicinal crops could be successfully grown on heavy metal polluted soils and under atmospheric pollution as substitutes for some other edible crops.

Table 4: Small RNAs responsive to biotic and abiotic stress and to nutrient deprivation in *Arabidopsis*

Small RNA	Conditions tested	Response	Validate target genes
miR398	Treated with diverse oxidative stress-causing agents such as high light levels, Cu^{2+}, Fe^{3+} and methyl viologen	Down-regulated	At1g08830 (Superoxide dimsutase 1, CSD1) At2g28190 (Superoxide dimsutase 2, CSD2) At3g15640 (Cytochrome c oxidase subunit V)
miR393	(a) Cold, dehydration, NaCl, and ABA stress (b) Leaves treated with bacterial flagellin 22 (c) Leaves infiltrated with *Pseudomonas syringea* pv. tomato (DC3000hrcC)	Up-regulated Up-regulated Up-regulated	At1g12820 (F-box protein, AFB3) At3g26810 (F-box protein, AFB2) Atg62980 (F-box receptor, AFB1) At3g23690 (basic helix-loop-helix family protein)
miR395	Low sulfate levels in the media	Up-regulated	At5g10180 (Sulfate transporter, AST68) At3g22890 (ATP sulfurylase 1, APS1) At4g14680 (ATP sulfurylase 3, APS3) At5g43780 (ATP sulfurylase 4, APS4)
miR399	Low phosphate levels in the media	Up-regulated	At2g33770 (Ubiquitin conjugating enzyme-E2, UBC24) At3g54700 (Phosphate transporter)
SRO5-P5CDH natsiRNA	Salinity (NaCl) stress	Up-regulated	At5g62530 (Pyrroline-5-carboxylate dehydrogenase, P5CDH)
natsiRNAATGB 2	Leaves infiltrated with *P. syringea* pv. tomato (avrRpt2)	Up-regulated	At4g35850 (a member of pentatricopeptide repeat containing protein family, PPRL)

(Sunker et al., 2007)

6. Oxidative stress (reactive oxygen species, ozone)

Reactive oxygen intermediates (ROIs) are partially reduced forms of atmospheric oxygen (O_2). They typically result from the excitation of O_2 to form singlet oxygen (O_2^1) or from the transfer of one, two or three electrons to O_2 to form, respectively, a superoxide radical (O_2^-), hydrogen peroxide (H_2O_2) or a hydroxyl radical (HO^-). In contrast to atmospheric oxygen, ROIs are capable of unrestricted oxidation of various cellular components and can lead to the oxidative destruction of the cell. There are many potential sources of ROIs in plants. Some are reactions involved in normal metabolism, such as photosynthesis and respiration. These are in line with the traditional concept, considering ROIs as unavoidable byproducts of aerobic metabolism. Other sources of ROIs belong to pathways enhanced during abiotic stresses, such as glycolate oxidase in peroxisomes during photorespiration. However, in recent years, new sources of ROIs have been identified in plants, including NADPH oxidases, amine oxidases and cell-wall-bound peroxidases. These are tightly regulated and participate in the production of ROIs during processes such as programmed cell death and pathogen defense. Whereas, under normal growth conditions, the production of ROIs in cells is low (240 μM $s^{-1}O_2^{\,-}$ and a steady-state level of 0.5 μMH_2O_2 in chloroplasts), many stresses that disrupt the cellular homeostasis of cells enhance the production of ROIs (240–720 μM $s^{-1}O_2^-$ and a steady-state level of 5–15 μMH_2O_2). These include drought stress and desiccation, salt stress, chilling, heat shock, heavy metals, ultraviolet radiation, air pollutants such as ozone and SO_2, mechanical stress, nutrient deprivation, pathogen attack and high light stress (Mittler, 2002). Pine (Analgesic, Anodyne, Antibacterial, Appetite Depressant/Obesity, Aromatic, Cancer and Depurative) root infected with mycorrhization stimulated the phenolic defence system against reactive oxygen species (ROS) caused by metal contamination (Schützendübel and Polle, 2002). Most of the medicinal plants are having defense system against ROS. However, not much attention drowns on the line of work. However, some of the medicinal and aromatic plans like Patchouli, *Calotropis procera*, *Tinospora cordifolia*, *Commiphora wightii*, *Cassia* *angustifolia*, *Withania somnifera*, *Aloe barbadensis*, *Pedalium murex*, *Boerhaavia diffusa*, *Cyperus sps*, *Tribulus terrestris*, *Prosopis cineraria*, *Capparis deciduas*, *Solanum khassianum* and *Trachyspermum ammi* could withstand under such stress and the mechanism needs to be studied. However, *Withania somnifera* is highly susceptible for oxidative stress or the hypoxia (Aishwath and Tarafdar, 2007).

7. Wind (sand and dust particles in wind)

Like all living members of the biosphere, spices, medicinal and aromatic plants are not immune to the effects of climate change. Climate change is causing noticeable effects on the life cycles and distributions of the world's vegetation, including wild MAPs. Some MAPs are endemic to geographic regions or ecosystems particularly vulnerable to climate change, which could put them at risk. Concerns regarding the survival and genetic integrity of some MAPs in the face of such challenges are increasingly being discussed within various forums. It has been noted that common medicinal plants of the Pacific islands include noni (*Morinda citrifolia*, Rubiaceae), naupaka (*Scaevola* spp., Goodeniaceae), kukui (*Aleurites moluccana*, Euphorbiaceae), and milo (*Thespesia populnea*, Malvaceae), these and other medicinal plant species of the area grow relatively fast, have high reproduction rates, and are typically resistant to salt water and wind, making them more resilient to some of the predicted effects of global climate change. According to chair of the Mediterranean Islands Plant Specialist Group of the IUCN, stated that medicinal plants of the Mediterranean islands do not appear to be under any considerable threat from conditions of climate change. Most wild collected MAPs, such as thyme (*Thymus* spp., Lamiaceae) and rosemary (*Rosmarinus* spp., Lamiaceae), datura (*Datura alba Solaneceae*) etc are rather widespread and located at lower altitudes, making them less vulnerable under such conditions (Cavaliere, 2009).

Table 5: Influence of alkali irrigation water on medicinal plants

Name of the Plant	Visual changes in colour and morphology of plants
Chlorophytum borivilianum	Leaf chlorosis during conducive weather and burning of leaf tips and margins under dry-spell or bright sunny days.
Bacopa monnieri	Regular irrigation for one year leads to death of plants.
Centella asiatica	Chlorosis in leaves, rolling of leaf form the funnel shape.
Barleria prionitis	Seedlings are highly susceptible for chlorosis. black spot in the leaves appears due to death of the tissue.
Pedalium murex	Leaf burning, chlorosis, reduced growth and early death.
Rauvolfia serpentine	Stunted growth, initially inter-venial chlorosis, leaf burning and bunchy top.
Piper longum	Chlorosis in rainy season and burning and curling of leaf margin in the dry spell.
Commiphora weightii	Prolong use of this water affect the growth of the plant and partial chlorosis in leaves during rainy seasons.
Asparagus, Species	Chlorosis in young leaves and bunchy top of plants.
Alpinia calcarata & *speciosa*	Chlorosis in young leaves with green midribs. Burning and inward rolling of leaf margin and dwarfism.
Cassia tora	Inter-venial chlorosis in leaves with pale yellow colour.
Murraya paniculata	Reduction of inter-nodal distance and chlorosis in leaves.
Plumbago zeyilanica	Cap shape of leaf, reduction in size and chlorosis in leaf.
Elettaria cardamomum	Growth reduction, inter-venial chlorosis occurs with pale yellow colour to white.
Catharenthus species	Inter-venial chlorosis appears in the leaves rib. Inter-nodal distance reduced resultant bunchy top of plants.
Citrus medica	Young leaves showed inter-venial chlorosis and curling.
Andrographis paniculata	Reduced plant growth, inter-venial chlorosis, plant shape become pyramidal type.
Hibiscus subdariffa	Seedlings are highly susceptible for chlorosis

Aishwath (2005a)

8. Nutrient deprivation in soil

Rise in temperature leads to fast mineralization of soil organic matter and release of nutrients in soil leads to losses of nutrients through water runoff. It has been estimated that India is loosing about 8.2 million tonnes of nutrients annually (Singh 1998). Lower fertility and moisture stress which offer a limited choice for increasing crop production under varying rainfall situation with climate change. Coriander, cumin, fenugreek, aromatic grasses, peppermint, davana, lavender and geranium are suitable for nutritionally eroded soil and some of them have association with VAM leads to effective utilization of available nutrients and moisture by them. It is well known fact that grasses can squeeze the soil by extracting the nutrients with their complex root system. Here, vast potential of aromatic grass could be harvested by utilizing nutritionally eroded soil with limited water (Aishwath *et al.*, 2008). Some of the seed spices and aromatic plants have lower requirement of nutrient can be grown on lower fertile soil (Table 2). It has also been reported that VAM simulate plant growth by physiological effects other than by enhancement of nutrient uptake or by reducing the severity of diseases caused by soil borne pathogens (Dehne 1982). The responsiveness of VAM to the host specific seed spices and aromatic plant is given in Table 3 (Aishwath and Tarafdar, 2007). Recently, possibilities have been explored for the cultivation of rose scented geranium (*Palargonium sps*) in semi-arid conditions by multiple cuttings/harvesting (Kothari *et al.,* 2004). To cope up against the nutrient deprivation stress with climate change, there is a need to find out the gene responsive to nutrient stress. Recently some of the studies showing stress regulation of miRNAs and endogenous siRNAs, as well as from target predictions for some miRNAs. There have been small RNAs to biotic and abiotic stress and nutrient deprivation were reported in *Arabidopsis thaliana* one of the medicinal plants used for sour throat. The small RNAs responsive to overcome biotic and abiotic stress related to nutrients deprivation are given in Table 4 (Sunkar *et al.,* 2007).

Detriments on spices medicinal and aromatic plants

The most obvious detriment concerning abiotic stress involves farming. It has been claimed by one of the study that abiotic stress causes the most crop loss of any other factor and that most major crops are reduced in their yield by more than 50% from their potential yield (Wang *et al.*, 2007). It has also been speculated that this yield reduction will only worsen with the dramatic climate changes expected in the future (Lane and Jarvis, 2007). Because abiotic stress is widely considered a detrimental effect, the research on this branch of the issue is extensive. A plant's first line of defense against abiotic stress is in its roots. If the soil holding the plant is healthy and biologically diverse, the plant will have a higher chance of surviving stressful conditions (Brussaard, 2007). Facilitation, or the positive interactions between different species of plants, is an intricate web of association in a natural environment. It is how plants work together. In areas of high stress, the level of facilitation is especially high as well. This could possibly be because the plants need a stronger network to survive in a harsher environment, so their interactions between species, such as cross-pollination or mutualistic actions, become more common to cope with the severity of their habitat (Maestre, 2007).

Extreme weather conditions throughout Europe are impacting medicinal plant production from seeding to harvesting. The extremely dry soil conditions resulting from recent abnormally and hot summers has prevented successful fall reseeding of some medicinal plants, such as chamomile in Germany and Poland. Fennel (*Foeniculum vulgare*) was recorded as having no yield at all in Bulgaria, due to drought conditions during the spring. Serbia's long and dry summers, which have been accompanied by other extreme weather conditions such as strong rains and winds, have sometimes made it impossible for harvesters to perform second cuttings of the aerial parts of cultivated herbs such as peppermint. Hungary, meanwhile, has been experiencing increasingly severe flooding for the past 3 to 4 years, which has led to yield deficits for both fennel and anise (*Pimpinella anisum*). Medicinal plants of the Sahel include hibiscus (*Hibiscus sabdariffa*), myrrh (*Commiphora africana*), frankincense (*Boswellia* spp.), baobab (*Adansonia digitata*), moringa (*Moringa oleifera*), and various aloes (*Aloe* spp.). Environmental degradation and future drought from climate change could have devastating effects on the region's already suffering ecosystems and harvesting capabilities. Hail and rainstorms have also damaged psyllium (*Plantago ovata*) and cumin (*Cuminum cyminum*) crops in India. The destruction of Indian psyllium crops from hail and rainstorms resulted in a smaller than usual annual yield for 2008. Heavy monsoon rainfall occurred earlier than usual in Northern India and reportedly damaged wild mint (*Mentha arvensis*) crops in 2008 (Cavaliere, 2009). Senna (*Cassia angustifolia*) is highly sensitive for the excess moisture. Even over night stagnation of water leads to wilt and root turns black at collar zone. During 2008 heavy yield loss of coriander, cumin and fennel was experienced by the frost. However, kalijeeri (*Centetratherum antihelminthicum*) crop was totally damaged by frost (Aishwath *et al.*, 2010a). Some of the medicinal and aromatic plants are highly susceptible to sodic water leads to heavy yield losses by morphological impairments are given in Table 5 and 6 (Aishwath, 2005a).

Table 6: Influence of alkali irrigation water on aromatic plants

Name of the Plant	Visual changes in colour and morphology of plants
Cymbopogon winterianus	Initial establishment of plant is problematic with this water. Initially inter-venial and then leaves turn in to complete white. Plant mortality occurs at the severity of chlorosis.
Cymbopogon flexuousus	The irrigated plants showed inter-venial chlorosis. Reduction of growth, biomass production and oil yield.
Cymbopogon martinii	Seedlings are susceptible for chlorosis to this irrigation water.
Other *Cymbopogon species*	Some local selections, which are having high potential of biomass and oil yield production, highly susceptible for the chlorosis caused by this irrigation water resultant lower growth and yield
Hibiscus abelmoschus	Reduced growth and yield was observed due to chlorosis in plants. Chlorosis observed in all the three seasons (winter, summer and rainy). However, high degree of chlorosis found in the rainy season.
Pandanus odoratissimus	It shows stunted growth and chlorosis in leaves at the initial stage and after establishment of 3-4 years bushes did not show any adverse impact on growth and development of plants.
Cestrum nocturnum	Midribs of the leaves remain green rest of the part appears chlorotic. Leaf surface becomes uneven and shows depressions and indentations on the leaf surface. Leaf turn into boat shape by curling inward.
Coriandrum sativum	Initially inter-venial chlorosis appears and at the severity complete plant turns into white. Plant mortality occurs at the severity of chlorosis.

Aishwath and Nibauria (2009) and Aishwath and Anwer (2010a)

Future Line of Research

1. Development of drought, heat, salinity tolerant, short duration and photo insensitive lines having maximum PS II sensitivity to light and temperature, stomatal response to vapor pressure density and wind action, chlorophyll content and dry matter partitioning to economic yield.
2. With changing climatic conditions atmospheric carbon di oxide has become an alarming issue studies to be under taken to assess its impact on growth, development and productivity of crops.
3. Biological wind barrier, crop diversification and silvipastoral system should be developed for arresting dust, wind speed and frost.
4. Cultural practice should be developed according to variety specific rather to crop specific.
5. Modeling should be done for the degree of severity of abiotic stress to cope up from the anticipated future climate change.
6. For the improvement of terrestrial agricultural ecosystem, soil physical chemical and biological environment should be strengthening.
7. Any system as close to the nature so is the sustainable. Therefore, natural or ecological (in new terminology ‘Conservation Agriculture’, ‘Organic Farming’ etc.) farming should be encouraged.
8. Nutrient efficient crops and their varieties should developed and studied their economizing efficiency through dynamics of nutrients in soil-plant system.

REFERENCES

Aishwath, O.P. and Nibauria, S.V.S. (2009) Problematic soil resource utilization through aromatic plants. *Ecology, Environment & Conservation* **15**(4): 32-41.

Aishwath, O.P. (2004) Growth yield and mineral composition of *Withania somnifera* grown on saline black soil. *Indian Journal of Agricultural Chemistry* **37**(1):1-8.

Aishwath, O.P. (2005a) Appraisal of underground water in four consecutive years at NRC MAP, Boriavi (Gujarat) and impact of its irrigations on medicinal and aromatic plants. *Ecology, Environ. & Conserv.* 11: 373-380.

Aishwath, O.P. (2005b) Coefficient of variation and correlation coefficient in underground water quality parameters in and adjoining municipal area of Boriavi, Gujarat. *Pollution Research* **24**: 9-17.

Aishwath, O.P. (2009) Mineral composition and autecological study of *Plantago ovata* in various soil textural environments of Fluventic Ustochrepts and Vertic Ustochrepts. *Ecology, Environment & Conservation* **15** (1): 181-187.

Aishwath, O.P. and Anwer, M.M. (2010a) Lime induced chlorosis in *Coriandrum sativum*: First report in the world. *NRCSS E-Newsletter* **2** (5): 3-6.

Aishwath, O.P. and Anwer, M.M. (2010b) Natural resource management through seed spices and aromatic plants. In: *Recent Advances in Seed Spices* (Eds Y.R. babu, R.K. Jaiman, K.D. Patel, N.R. Patel & S.B.S. Tikka). Pub. Daya Publishing House, New Delhi, India. pp 107-118.

Aishwath, O.P. and Pal, B. (2000) Performance of palmarosa (*Cymbopogon martinii* var Motia) under various soil texture and salinity levels. *Indian Perfumer* **44**: 285-290.

Aishwath, O.P. and Pal, B. (2004) Mineral composition of palmarosa (*Cymbopogon martinii*), soil EC and pH as influenced by saline water irrigation in texturally different soils. *Journal of Gujarat Society of Agronomy & Soil Science* **4**: 42-47.

Aishwath, O.P. and Tarafdar, J.C. (2007) Role of organic farming in medicinal and aromatic plants. In: *"Organic Farming and Sustainable Agriculture"* (Eds. Tarafdar *et al.*, 2007). Publisher - Scientific Publisher, Jodhpur. pp 135-185.

Aishwath, O.P., Meena, S.S., Kant, K., Sharma Y. K. and Anwer, M.M. (2010a). Climate Change and Seed Spices. In: *Challenges of Climate Change-Indian Horticulture* (Eds, H.P. Singh, J.P. Singh, and S.S. Lal). Published by Westville Publishing House, New Delhi. pp 85-89.

Aishwath, O.P., Pal, B. and Singh, A.K. (1990) Effect of soil texture and water salinity on the growth, dry matter production, nutrients uptake and oil content of palmarosa (*Cymbopogon martinii*). *Journal of Agricultural Sciences Research* **32**: 45-47.

Aishwath, O.P., Vashishtha, B.B. and Malhotra, S.K. (2008) Scope of Production of Aromatic Plants in Arid and Semiarid Regions. In *Spices and Aromatic Plants*' (Eds. Z.S. Solanki, G.N. Parihar, B.S. Rathore and S.R. Kumar). Publisher, ZDR, ARS Mandor, Jodhpur, Rajasthan. pp 147-162.

Aishwath, O.P., Mehta, R.S., Lal, G., Anwer, M.M., Dagar, J.C., Yadav, R.K. and Singh, R. (2010b) Growing seed spices a boon for problematic areas. *Indian Horticulture* **55** (4):19-21.

Amudha, K., Sakthivel, N. and Mohamed, M.Y. (2011) Rice - A novel food with medicinal value. *Agriculture Reviews* **32** (3): 222-227.

Angelone, M, Bini, C. (1992) Trace elements concentrations in soils and plants of Western Europe. In: *Biogeochemistry of trace metals* (ed. Adriano, D.C.). Boca Raton, FL: Lewis Publishers 19–60.

Anwar, M., Patra, D.D. and Singh, D.V. (1996) Influence of soil sodicity on growth oil yield and nutrient accumulation in vetiver (*Vetiveria zizanioides*). *Annals of Arid Zone* **35:** 49-52.

Ashraf, M. (1994) Breeding for salinity tolerance in plants. *Critical Reviews in Plant Sciences,* 13: 17–42.

Ashraf, M. and Harris, P.J. (2004) Potential biochemical indicators of salinity tolerance in plants. *Plant Science* **166:** 3–16.

Bray, E.A., Bailey-Serres, J. and Weretilnyk, E. (2000) Responses to abiotic stresses, in: *Biochemistry and Molecular Biology of Plants* (Eds. W. Gruissem, B. Buchannan, R. Jones), American Society of Plant Biologists, Rockville, MD, pp. 158–249.

Britt, A.B. (1999) Molecular genetics of DNA repair in higher plants. *Trends Plant Science* **4:** 20–24.

Brussaard, L., Peter C., Ruiter, D. and Brown, G.G. (2007) Soil biodiversity for agricultural sustainability. *Agriculture Ecosystems and Environment* **121:** 233–244.

Cavaliere, C. (2009) The effects of Climate Change on Medicinal and Aromatic Plants (American Botanical Council). *Herbal Gram* **81:** 44-57.

Chopra, L.C., Abrol, B.K. and Handa, K.L. (2003) Medicinal plants of the arid zone. Publisher Today & Tomorrow printers and Publishers. pp 11-55.

Cleland, E.E., Chuine, I., Menzel, A., Mooney, H.A. and Schwartz, M.D. (2007) Shifting plant phenology in response to global change. *Trends in Ecology and Evolution* **72 (7):** 357-364.

Dagar, J.C. (2007). Alternative land uses in areas with water scarcity. In, *On-farm land and water management* (A Compilation of National Training Course) pp 154-165.

Dagar, J.C. (2008) Cultivation of Medicinal and Aromatic Plants with Poor Quality Water. In: *Diagnosis and Management of poor quality water and salt affected Soils* (eds. Lal *et al*). Central Soil Salinity Research Institute, Karnal. pp 299-302.

Dagar, J.C., Tomar, O.S., Kumar, Y. and Yadav, R.K. (2004). Growing three aromatic grasses in different alkali soils in semi-arid regions of northern India. *Land degradation and development* **15 :** 143-151.

Dehne, H.W. (1982) Interaction between vesicular arbuscular mycorrhizal fungi and plant pathogens. *Phytopathology* **726:** 1115-1119.

Dudal, R. (1976) Inventory of Major Soils of the World with Special Reference to Mineral Stress. *Cornell Univ. Agric. Exp. Stn. Ithaca* **3:** 89-96.

Farooqi, A.A. and Sreeramu, B.S. (2001) Ambrette, Chamomile, Dill, Lavender, and Palmarosa. In: *cultivation of medicinal and aromatic plants*. Pub. Univ. Press (India) Ltd. Hyderabad. pp 295-423.

Foolad, M.R. (1999) Comparison of salt tolerance during seed germination and vegetative growth in tomato by QTL mapping. *Genome* **42:** 727-734.

Foolad, M.R. and Lin, G.Y. (2001) Relationship between cold tolerance during seed germination and vegetative growth in tomato: analysis of response and correlated response to selection. *Journal of American Society of Horticultural Science* **126:** 216-220.

Foolad, M.R., Zhang, L. and Subbiah, P. (2003) Genetics of drought tolerance during seed germination in tomato: inheritance and QTL mapping. *Genome* **46:** 536–545.

Framji, K.K. (1974) International Commission on Irrigation and Drainage bulletin. pp 36-41.

Galloway, J.N. Thornton, J.D., Norton, S.A., Volcho, H.L. and McLean, R.A. (1982) Trace metals in atmospheric deposition: a review and assessment. *Atmospheric Environment* **16:** 1677.

Garg, V.K., Singh, P.K and Katiyar, R.S. (2000) Spices and aromatic plants. In: Proc. *Centennial conference on spices and aromatic plants* (20-23 September, 2000), Kalicut, Kerla, India. pp 133-138.

Gautam, R.K. and Nayak, A.K. (2008) Screening and Utilization of Salt Tolerant Genotypes of Medicinal Crop under Sodic Soils Conditions. In: *Diagnosis and Management of poor quality water and salt affected Soils* (eds. Lal *et al*). Central Soil Salinity Research Institute, Karnal. pp 296-298.

Gosain, A.K., Rao, S. and Basuray, D. (2006) Climate change impact assessment on hydrology of Indian river basins. *Current Science* **90**(3): 10.

Grewal, H.S. (2010) Response of wheat to subsoil salinity and temporary water stress at different stages of the reproductive phase. *Plant & soil* **330:** 103-113.

Grill, E., Winnacker, E.L. and Zenk, M.H. (1987) Phytochelatins, a class of heavy-metal-binding peptides from plants, are functional analogous to metallothioneins. In: *Proceedings of the National Academy of Sciences*, USA. **8:** 439-443.

Grover, A. Aggarwal, P.K., and Kapoor, A. (2003) Addressing abiotic stresses in agriculture through transgenic technology. *Current Science* **84**(3): 355-367

Gupta, R. and Gulati, B.C. (1965) Salt tolerance in *Cymbopogon nardus* (Lin) Rendle (*Citronella* cylon type) possibilities of commercial cultivation in *ushar* lands. Proc. Sem. *Sea salt and Plants*, held at Bhavnagar. pp 100-106.

Gupta, R.K., Bhardwaj, S.P. and Mittal, S.P. (1998) Management of degraded lands in the Himalayas. In, *Technologies for waste land development* (Eds Abrol, I.P. and Dhurva Narayana, V.V.). Pub. Information Div. ICAR, KAB, New Delhi pp 196-208.

Gupta, S.K. and Gupta, I.C. (1997) Crop tolerance to saline conditions. In: *Management of saline soils and water*. Scientific Publishers, Jodhpur, India. pp 99-117.

Hamdia, M. A. and Shaddad, M. A. K. (2010) Salt tolerance of crop plants. *Journal of Stress Physiology & Biochemistry* **6** (3): 64-90.

Hamdia, M.A. (2008) Review on the physiology of senescence and abscission. *Current Topics in Plant Biology* **9:** 45-67.

Hamdia, M.A., and Shaddad, M.A.K. (1996) Comparative effect of sodium carbonate, sodium sulphate and sodium chloride on growth and related metabolic activities of pea plants. *Journal of Plant Nutrition* **19:** 717-728.

Hasegawa, P.M., Bressan, R.A., Zhu, J.K., Bohnert, H.J. (2000) Plant cellular and molecular responses to high salinity. *Annual review of plant physiology and plant molecular biology.* **51:** 463–499.

Jansen, M.A.K., Gaba, V. and Greenberg, B.M. (1998) Higher plants and UV-B radiation: balancing damage, repair and acclimation, *Trends Plant Sciences* **3:** 131-135.

Jenkins, S., Edward, G., Lennard, B., Rengel, Z. (2010) Impacts of water logging and salinity on Puccinellia (*Puccinellia ciliate*) and wheat grass (*Thinopgrum ponticum*) zonation consaltland with a shallow-water table, plant growth and Na^+ and K^+ concentrations in the leaves. *Plant & Soil* **329:** 91-104.

Jhony, A.K. and Ravindran, P.N. (2005) Over 225 HI-Yielding spice varieties in India. Part III. *Spice India* **18**(6)**:** 39-52.

Jones, H.G. Jones, M.B. (1989) Introduction: some terminology and common mechanisms. In: *Plants Under Stress* (eds. Jones, *et al*). Cambridge University Press, Cambridge, pp. 1-10.

Kelly, W.P. (1963) Use of saline irrigation water. *Soil Science* **96:** 305-391.

Kothari, S.K., Vijay Kumar, Y., Bhattacharya, A.K. and Ramesh, S. (2004) Harvest management in rose-scented geranium (*Pelargonium sps.*) for higher essential oil yield and superior quality under semi-arid tropics. *Archives of Agronomy & Soil Science* **50:** 593-600.

Kumar, R., Singh R.D. and Sharma, K.D. (2005) Water resources of India, *Current Science* **89**(5)**:** 794–811.

Lane, A. and Jarvis, A. (2007). Changes in Climate will modify the Geography of Crop Suitability: Agricultural Biodiversity can help with Adaptation. *Ecology Journal*, 4(1): 1-12.

Lantzy, R.J. and Mackenzie, F.T. (1979). Atmospheric trace metals: global cycles and assessment of man's impact. *Geochimica et Cosmochimica Acta* **43:** 511.

Maestre, F. T., Cortina, J. and Bautista, S. (2007) Mechanisms underlying the interaction between *Pinus halepensis* and the native late-successional shrub *Pistacia lentiscus* in a semi-arid plantation. *Ecography* **27:** 776–786.

Mahajan, S. and Tuteja, N. (2005) Cold, salinity and drought stresses: An overview. Archives of *Biochem. & Biophysics* **444:**139–158.

Mittler, R. (2002) Oxidative stress, antioxidants and stress tolerance. *Trends in Plant Science* **7** (9)**:** 405-410.

Molinier, J., Edward, J., Oakeley, Niederhauser, O., Kovalchuk, I. and Hohn, H. (2005) Dynamic response of plant genome to ultraviolet radiation and other genotoxic stresses. *Mutation Research* **571:** 235–247.

Munns, R., Tester, M. (2008) Mechanisms of Salinity Tolerance. *Annual Review of Plant Biology* **59:** 651-681.

Murty, K.S. (2002) River water sharing: India's problems. *International Association of Hydrological Sciences Publication* **274:** 323–328.

Pal, B., Singh, K.K., Jadaun, S.P.S. and Parmar, A.S. (1989) Effect of water salinity on herb and oil yield and composition of some *Cymbopogon species*. *Indian Perfumer* **33:** 196-199.

Pal. B., Singh, A.K., Singh, P.K. and Singh, R.P. (1993) Effect of saline water on herb, oil yield and composition of palmarosa (*Cymbopogon martinii* Var Motia). *Indian Perfumer* **37:** 267-269.

Parmesan C. and Yohe G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **421:** 37-42.

Patra, D.D. and Singh D.V. (1995) Utilization of salt affected soil and saline sodic irrigation water for cultivation of medicinal and aromatic plants. *Current Research on Medicinal and Aromatic Plants* **17:** 378-381.

Patra, D.D., Anwar, M. and Singh, D.V. (1992) Herb yield, essential oil yield and nutrient accumulation by palmarosa under saline water irrigation. Abstract of technical paper presented at the conference on symposium on Environmental Soil Science, Canadian Society of Soil Science, August 8-13, Alberta, Canada pp 36.

Patra, D.D., Prasad, A., Anwar, M., Singh, D., Chand, S., Ram, B., Katiyar, R.S. and Kumar, S. (2002) Performance of lemongrass cultivars intercropped with chamomile under sodic soil with different levels of gypsum application. *Communication of Soil Science Plant Analysis* **33:** 1707-1721.

Prakasa Rao, E.V.S. (1992) Fertilizer management in medicinal and aromatic crops. In: *Nontraditional Sectors for fertilizer Use* (Eds Tandan, H.L.S). Fertilizer Development and Consultation organization, New Delhi, India. pp. 73-93.

Prakasha Rao, E.V.S. (1993) Nutrient management in some important tropical aromatic crops present and future. *Indian Perfumer* **37:** 35-39.

Prasad, A. and Chattopadhyay, A. 1999. Growth and yield of Japanese mint (*Mentha arvensis*) in acid sedentary and slightly alkaline soil. *Indian Perfumer* **43:** 9-14.

Prasad, A. and Singh, D.V. (1998) Effect of organic amendments on yield of palmarosa (*Cymbopogon martinii* Roxb. Wats) var Motia and chemical properties of sodic soil. *Indian perfumer* **42:** 21-26.

Rao, G.G., Nayak, A.K., Chinchmalatpure, A.R. and Khandelwal, M.K. (2001) Yield of dill (*Anethum graveolens*) on saline black soils of different unirrigated farm sites of Bhal area in Gujarat. *Indian Journal of Agricultural Sciences* **71:** 711-712.

Rao, G.G., Nayak, A.K., Chinchmalatpure, A.R. Singh, R. and Tyagi, N.K. (2001) Resource characterization and management options for salt affected black soils of agro-ecological regionV of Gujarat state. pp 48-53.

Rontein, G. Basset and Hanson, A.D. (2002) Metabolic engineering of osmoprotectant accumulation in plants. *Metabolic Engineering* **4:** 49–56.

Salt, D.E., Blaylock, M., Kumar, N.P.B.A., Dushenkov, V., Ensley, B.D., Chet, I. and Raskin, I. (1995) Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. *Biotechnology* **13:** 468–474.

Schützendübel, A. and Polle, A. (2002) Plant responses to abiotic stresses: heavy metal-induced oxidative stress and protection by mycorrhization. *Journal of Experimental Botany* **53**(372)**:**1351-1365.

Schützendübel, A. Schwanz, P. Teichmann, T. Gross, K., Langenfeld-Heyser, R., Godbold, D.L. and Polle, A. (2001) Cadmium-induced changes in antioxidative systems, H_2O_2 content and differentiation in pine (*Pinus sylvestris*) roots. *Plant Physiol.* **127:** 887–892.

Sehgal, J.L., Saxena, R.K. and Pofali, R.M. (1998) Degraded soil-their mapping through soil surveys. In, *Technologies for waste land development* (Eds Abrol, I.P. and Dhurva Narayana, V.V.). Pub.

Information Div. ICAR, KAB, New Delhi pp 1-20.

Sharma P.C., Mishra, B., Singh R.K. and Singh, Y.P. (2001) Variability in the response of spinach, fenugreek and coriander to alkalinity and salinity stresses. *Indian Journal of Plant Physiology* **6:** 329-333.

Shiva, M.P., Lehri, A. and Shiva, A. (2002) Introduction, Calamus, Cardamom, Clove Kewada Mint and Vetiver. In. *Aromatic and Medicinal Plants*. Publisher, International Book Distributors, Dehra Dun, India. pp 67-307.

Singh, D.V. and Anwar, M. (1985). Effect of soil salinity on herb and oil yield and quality of some *Cymbopogons species*. *Journal of the Indian Society of Soil Science* **33:** 362-365.

Singh, G. and Samra, J.S. (2006) Agricultural drought and management strategies. In: *Drought management strategies in India* (eds. Samra *et al.*). Natural Resource Management Divition, Indian Counicil of Agricultural Research, New Delhi. pp 155-182.

Singh, R. (1999) Lavaniya jal aur mrda mai sounf ke kheti. Phal phool. Oct-Dec. pp 30-35.

Singh, R., Bhargava, G.P., Singh, R. (1995) Response of safflower (*Carthamus tinctorius*) and dill (*Anethum graveolens*) to soil salinity. *Indian Journal of Agricultural Sciences* **65:** 442-444.

Singh, R.P. (1998) Land degradation problems and their management in semi-arid tropics. In, *Technologies for waste land development* (Eds Abrol, I.P. and Dhurva Narayana, V.V.). Pub. Information Div. ICAR, KAB, New Delhi. pp 125-136.

Sunkar, R., Chinnusamy,V., Zhu, J. and Zhu, J.K. (2007) Small RNAs as big players in plant abiotic stress responses and nutrient deprivation. *Trends in Plant Sciences* **12**(7)**:** 1360-1385.

Ura, K. and Hayes, J.J. (2002) Nucleotide excision repair and chromatin remodeling. *European Journal of Biochemistry* **269:** 2288–2293.

Valtcho, D.Z., Lyle E. C. and Baoshan, X. (2006) Effects of Cd, Pb, and Cu on growth and essential oil contents in dill, peppermint, and basil. *Environmental and Experimental Botany* **58:** 9-16.

Valtcho, D.Z., Lyle, E. C., Baoshan, X., Niels, E. N. and Andrew, W. (2008) Aromatic plant production on metal contaminated soils. *Science of the Total Environment* **395:** 51-62.

Vonarx, E.J., Mitchell, H.L., Karthikeyan, R., Chatterjee, I. and Kunz, B.A. (1998) DNA repair in higher plants. *Mutation Researce* **400:** 187–200.

Walther GR, Post E, Convey P, Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O. and Bairlein, F. (2002) Ecological responses to recent climate change. *Nature* **416:** 389-395.

Wang, W., Vinocur, B. and Altman, A. (2007) Plant responses to drought, salinity and extreme temperatures towards genetic engineering for stress tolerance. *Planta* **218:** 1-14.

Zhang, W.J. and Björn, L.O. (2009) The effect of ultraviolet radiation on the accumulation of medicinal compounds in plants. *Fitoterapia* **80**(4)**:** 207-218

Zheljazkov, V. and Jekov, D. (1995) Heavy metal content in some essential oils and plant extracts. In: *Proc. International Symposium on Medicinal and Aromatic held on 1 November 1995* at *Amherst, USA, Published in Acta Horticulturae 2006*. pp 426.

Zhu, J.K. (2001 a) Plant salt tolerance. *Trends Plant Sci*ences **2:** 66–71.

Zhu, J.K. (2001 b) Cell signaling under salt, water and cold stresses. *Current Opinion in Plant Biology* **4:** 401– 406.

Zhu, J.K. (2002) Salt and drought stress signal transduction in plants. *Annual Review of Plant Physiology Plant Molecular Biology* **53:** 247–273.