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Impact of climate change on medicinal and aromatic plants: Review

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ABSTRACT

There has been worldwide changes in seasonal patterns, weather events, temperature ranges, and other related phenomena and all have been analyzed in partial, reported and attributed to global climate change. The negative impacts of climate change will become much more intense and frequent in the future—particularly if environmentally destructive human activities continue unabated, warned categorically by a number of experts in a wide range of scientific disciplines and interests. Medicinal and aromatic plants (MAPs) are not immune to the effects of climate change like all other living members of the biosphere. Clear signals are coming on climate change impact which is causing noticeable effects on the lifecycles and distributions of the world's vegetation, including wild MAPs across the world. This in turn causing some MAPs endemic to geographic regions or ecosystems which could put them at risk and are particularly vulnerable to climate change. Such serious issues and challenges are a continuous concern with regard to the survival and genetic integrity of some MAPs and are being discussed within various forum and platform. Further, such issues of climate change will definitely pose a more prominent or immediate threat to MAP species than other threats, however, scientists do not know whether climate change has the potential to exert increasing pressures upon MAP species and populations. Climate change impact may have a tremendous possible effect on MAPs particularly significant due to their value within traditional systems of medicine and as economically useful plants. At this stage, the future effects of climate change are largely uncertain more so with MAPs, but current evidence suggests that these phenomena are having an impact on MAPs and that there are some potential threats worthy of concern and discussion.

Key words: Adaptation, Climate change, Elevated CO_2, Medicinal and aromatic plants, Phenology, Plant constituents, Weather events

Earth's climate is warming at an unprecedented rate which is evidenced unequivocally. Sea levels are rising and impacting plant's growth and yield due to climatic effects. There are prolonged droughts in arid and semi-arid regions, increased flooding in mid to high latitudes, increase in extreme weather events etc. (Tack *et al*. 2015). There is a high risk of mass extinction of biodiversity as the planet warms and climate is changing more rapidly than species can adapt (Lindzen 1990, Das 2010a). There is need to understand the pattern of climate change which is one of the most important global environmental challenges and more specifically different types of impacts are to be understood and assessed, vulnerabilities need to be addressed, while adaptation strategies have to be developed through prioritizing the cause and the impacts (Cavaliere 2009, Courtney 2009). In the flip side of it, production enterprises and practices in agriculture are adapted to variability in local climate conditions, as farmers have specifically developed strategies for responding to weather patterns that have prevailed over a period of time in their given region (Marshall *et al*. 2015) and more so with medicinal plants like Isabgol, Asalio and many other important ones (Das 2010a, b) in arid and semi-arid condition.

To encourage nations to conserve their plant and animal species the United Nations declared 2010 as the Year of Biodiversity coupled with signing The Convention on Biological Diversity (CBD) more than a decade ago. But there is a continuous disappearance of species worldwide at a rapid rate claimed by local communities in various regions who have used medicinal plants for generations. Further, they said that these species are becoming difficult to find, which according to them could be due to climate change as a factor.

As a direct result of CBD, the Biological Diversity Act was enacted in 2002. A National Biodiversity Strategy and Action Plan (NBSAP) was prepared and subsequently a National Biodiversity Authority (NBA) was constituted. However, significant initiative under this Act by NBA for the conservation and sustainable use of medicinal plants is awaited or, more importantly, and the preservation of

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traditional knowledge, innovations and practices of indigenous and local communities or their wider application is needed. Any restrictions with regard to regulatory functions need to be understood and made viable on case to case basis with much emphasis to know the impact of climate change on MAPs.

Is there a big loss of medicinal plant species in India?

To systematically assess and enlist the decline and loss of medicinal plant species and to monitor and assess threat to wild populations of prioritized species (Denyer 2007), an institutional mechanism needs to be put in place. Article 8d of CBD specifically states: 'Promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings.' However, the Ministry of Environment and Forest (MoEF), has to have long-term programme, strategy or dedicated funding for monitoring viable populations and undertaking assessment of medicinal plants. National Medicinal Plants Board and Indian Council of Agricultural Research located at New Delhi may have to take the lead in this direction.

To further substantiate, on a relatively small scale, some efforts have been undertaken using IUCN Red List Categories and Criteria (Bhardwaj *et al*. 2007). According to such studies, 335 wild medicinal plants of India have been identified as being under various categories of threat of extinction ranging from Near Threatened, Vulnerable, Endangered to Critically Endangered. Eighty-four of these species of conservation concern were recorded in high volume trade (Bhardwaj *et al*. 2007). However, it's a continuous cycle and such kind of species are believed to be threatened, if sincere efforts are not taken.

Significant loss of diversity and its impact

Arguably, there are six plant species of high conservation concern. These are *Aconitum heterophyllum, Coscinium fenestratum, Decalepis hamiltonii, Picrorhiza kurroa, Saraca asoca* and *Taxus wallichiana* (Malcolm *et al*. 2006, Bhardwaj *et al*. 2007). These species are valuable medicinal plants which are currently being used in high quantities by India's herbal industry leading to rapid decline of their populations in wild and is of utmost concern. To reiterate the fact, the plant materials of these species are obtained entirely from the wild and their medicinal uses are described in the codified Indian systems of medicine, namely Ayurveda, Siddha and Unani.

These species are being used to treat many disease conditions, namely inflammatory, analgesic, anti-diarrhoeal, antipyretic, anti-diabetic, anti-cancer, in liver diseases as well as gynaecological disorders. The decline of these species will adversely affect the current usage for health care and treatment of such conditions. Further, their extinction will be an irreparable loss to the wild gene pool, which evolved over several millennia. It is to be understood that once lost, these species will not be reproducible through any synthetic means. It will be a huge loss for our future generations to suffer.

Losses because of climate change or because of over exploitation?

The decline and loss of wild populations of valuable wild Indian medicinal plants is due to the combined impact of habitat loss, its degradation, as well as over-exploitation (Goswami *et al*. 2006). Climate change is also cited as a reason but no serious studies have been undertaken in our country for medicinal plants in particular (Harish *et al*. 2012). However, a few recent studies, outside India, have speculated about the fragmentation and decline of wild populations of some plant species in the mountains ecosystems due to climate change (Thomas *et al*. 2004). Medicinal plants constitute around 40% of the known diversity of vascular plant species of India. Conservation of Indian flora merits high priority (Goswami *et al*. 2006). A national agenda for conservation of medicinal plants should be made.

Climate change challenges for medicinal plants

Although the terms "global warming" and "climate change" are often used interchangeably, "climate change" is often the preferred term of many environmental organizations and government agencies (IPCC 2007). Climate change refers to any significant change in measures of climate (such as temperature, precipitation, or wind) over an extended period of time (decades or longer). Global warming refers to an increase in the temperature of the atmosphere that can contribute to change in global climate patterns. The Intergovernmental Panel on Climate Change considers "climate change" to mean any change in climate over time, whether due to natural variability or as a result of human activity (IPCC 2007). The United Nations Framework Convention on Climate Change defines "climate change" as a change in climate that is attributable directly or indirectly to human activity that alters atmospheric composition.

The success of mankind's ability to meet the challenges of climate change will depend on how well it conserves the existing biodiversity of plants species including valuable medicinal and aromatic plants. Governments will have to act now, if plants are to continue to provide the resources and ecosystem services upon which all other species depend.

Wild plant conservation has three mutually dependent aims: (i) Maintaining plant species and their genetic diversity. (ii) Achieving sustainable use of wild plant resources. (iii) Securing plants and natural vegetation as providers of ecosystem services.

These aims are most likely to be achieved where efforts are focused on maintaining plants within robust ecosystems. However, the ability of national government to achieve these aims is under increasing pressure because of climate change; the impact of which is already visible at all levels of species' survival and conservation. A continuing and stoppable shift in the potential ranges of many plant species, causing them to become extinct in their existing locations is a reality. Many will find it difficult to 'follow the climate', lacking adequate means of dispersal and finding their paths being impeded by human destruction of wild habitats (Hawkins *et al*. 2008).

Like all living members of the biosphere, medicinal and aromatic plants (MAPs) are not immune to the effects of climate change. Climate change is causing noticeable effects on the lifecycles 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 (Neilson *et al*. 2005). Concerns regarding the survival and genetic integrity of some MAPs in the face of such challenges are increasingly being discussed within various fora at all levels to understand the gravity of the situation.

To believe it more scientifically, wild plants play a fundamental role in enabling national governments to sustain delivery of social and economic development and climate change magnifies the significance of this role. The critical factor to understand in securing sustainable management of national plant resources is how governments involve the people and groups for whom the resources have most value.

Climate change is affecting medicinal and aromatic plants around the world and could ultimately lead to losses of some key species. This conclusion is based on the research, observations, and opinions of multiple medicinal plant researchers and conservationists, as reported in the cover article of the latest issue of HerbalGram (Cavaliere 2008, 2009), the quarterly journal of the American Botanical Council (ABC).

The study has noted the endemic nature of the species to different regions or ecosystems that are especially vulnerable to climate change, such as Arctic and alpine regions, and could be at maximum risk (Cavaliere 2008). For example, *Rhodiola rosea* of the Canadian Arctic and snow lotus (*Saussurea laniceps*) of the Tibetan mountains are medicinal species that face significant threats from climate change.

The study further explores effects of climate change that appear to be impacting plants including medicinal plants throughout the world. For example, climate change has led to shifts in seasonal timing and/or ranges for many plants, which could ultimately endanger some wild medicinal plant populations. To add to the list, extreme weather events, meanwhile, have begun to impact the production and harvesting of various medicinal plants around the world. For instance, recent abnormally hot summers have prevented reseeding of medicinal plants such as chamomile (*Matricaria recutita*) in Germany and Poland, and increasingly severe flooding in Hungary has reduced harvests of fennel (*Foeniculum vulgare*) and anise (*Pimpinella anisum*) in that country (Pompe *et al*. 2008). Although, the primary focus of this article concerns medicinal plants, much of the threat to these plants includes aromatic plants harvested for their essential oils, which could be used for medicinal, fragrance, culinary, and/or other purposes (Cavaliere 2009, Tack *et al*. 2015).

Climate change impact on medicinal and aromatic plants

Climate change has become one of the greatest challenges to humankind and all other life on Earth. Worldwide changes in seasonal patterns, weather events, temperature ranges, and other related phenomena were reported and attributed to global climate change. Numerous experts in a wide range of scientific disciplines have warned that the negative impacts of climate change will become much more intense and frequent in the future—particularly if environmentally destructive human activities continue unabated (Walther *et al*. 2002). There is concern over its overall impact affecting secondary metabolites of many medicinal plants which are very important economically and commercially.

Although scientists do not know whether climate change poses a more prominent or immediate threat to MAP species than other threats, it does have the potential to exert increasing pressures upon MAP species and populations in the coming years. The possible effects on MAPs may be particularly significant due to their value within traditional systems of medicine and as economically useful plants. The future effects of climate change are largely uncertain, but current evidence suggests that these phenomena are having an impact on MAPs and that there are some potential threats worthy of concern and discussion.

Some studies have demonstrated that temperature stress can affect the secondary metabolites and other compounds that plants produce, which are usually the basis for their medicinal activity (Schar *et al*. 2004). But few studies were conducted *in-situ* or *ex-situ* to mimic conditions of global warming (Das *et al*. 1999).

The taste and medicinal effectiveness of some Arctic plants could possibly be affected by climate change (Gore 2006). It was noted that such changes could either be positive or negative, although it seems more likely that the effects would be negative since, secondary metabolites are produced in larger quantities under stressed conditions and for Arctic plants, warmer temperatures would likely alleviate environmental stress. However, the production of plants' secondary metabolites are influenced by diseases, competition between plants, animal grazing, light exposure, soil moisture, etc. and these factors may mitigate the effects of climate change on plants' secondary metabolites (Dean 2007).

Through collection of samples of medicinal plant species from Greenland, NordGen, an organization based in Alnarp, Sweden could go for preservation and evaluation of Angelica (*Angelica archangelica*, Apiaceae), yarrow (*Achillea millefolium*, Asteraceae), *Rhodiola rosea* (aka golden root, Crassulaceae), and thyme (*Thymus vulgaris*, Lamiaceae). These four MAPs are not currently endangered in Greenland, nor are they currently listed on the Convention in Trade in Endangered Species (CITES) appendices (Pal *et al*. 2004). However, collectors interested in preserving current plant genotypes from rapidly warming areas, such as Greenland, must do so before new genotypes arrive in response to climate change. Moreover, plant populations in Greenland are often isolated by the territory's many huge ice sheets, and this can limit the populations' available gene pools and subsequent abilities for genetically adapting to new climatic conditions. Capturing genetic diversity becomes increasingly important since it is possible that populations will lose genetic diversity in response to the changing environment.

Some cold-adapted plant species in alpine environments have begun to gradually climb higher up mountain summits—a phenomenon correlated with warming (Held *et al*. 2005). In some cases, these plants migrate upward until there are no higher areas to inhabit, at which point they may be faced with extinction. Additionally, the upward migration of plant species can lead to increased competition for space and resources, causing further stress among alpine plant populations.

A Global team found that useful Tibetan plants (predominantly medicinal plants) accounted for 62% of all plant species in the alpine Himalayan sites that they examined (Bhardwaj *et al*. 2007). Further, although overall species richness was found to decline with elevation from the lowest summits to the highest, the proportion of useful plants stayed approximately constant. This high percentage of useful plants confirms the importance of the Himalayas for Tibetan medicine and reflects the dangers posed by potential plant losses from climate change.

However, a few medicinal alpine species are restricted to the upper alpine zone, such as *Artemisia genipi* (Asteraceae) and *Primula glutinosa* (Primulaceae). These species may experience greater impacts from warming temperatures, possibly leading to local endangerment (Pal *et al*. 2004).

Medicinal and aromatic plants in other threatened regions

Although Arctic and alpine areas are experiencing some of the most rapid changes from global warming, other ecosystems are also considered particularly threatened by the ongoing effects of climate change, e.g. islands and rainforests (Dean 2007). Islands are considered especially at risk from rising ocean levels, in addition to changing temperatures and weather patterns. The world's oceans also absorb excess heat from the atmosphere, and as water warms it expands in volume which will similarly contribute to global sea level rise (Walther *et al*. 2002).

Despite these threats, experts have indicated that island MAPs may not be significantly affected by conditions related to climate change. Many of the plants used by island communities are common species that are widespread and highly adaptable.

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 (Law and Salick 2005, Walther *et al*. 2002).

Similarly, medicinal plants of the Mediterranean islands do not appear to be under any considerable threat from conditions of climate change (Yoon 1994). According to de Montmollin, most wild collected MAPs, such as thyme (*Thymus* spp., Lamiaceae) and rosemary (*Rosmarinus* spp., Lamiaceae), are rather widespread and located at lower altitudes, making them less vulnerable to climate change than plants with narrower ecological requirements (Parmesan and Yohe 2003). Rainforest ecosystems are also considered to be threatened by climate change. Climate modeling studies have indicated that these regions are likely to become warmer and drier, with a substantial decrease in precipitation over much of the Amazon (Neilson *et al*. 2005).

There is not much, if any, published evidence on MAPs that could be at risk in the rainforest from climate change, and experts are unable to comment on specific MAPs that may be vulnerable to climate change in rainforests. However, the expected loss of general biodiversity in the Amazon, as noted in the IPCC report, indicates the potential to lose both known and undiscovered MAP species (IPCC 2007).

Widespread effects of climate change

It appears that there is worldwide effects of climate change on plants. For instance, evidence has shown that climate change has been affecting vegetation patterns such as phenology (the timing of lifecycle events in plants and animals, especially in relation to climate) and distribution (Cleland *et al*. 2007). Some wild plants, including MAPs, have begun to flower earlier and shift their ranges in response to changing temperatures and weather. Shifting phenologies and ranges may seem of little importance at first glance, but they have the potential to cause great challenges to species' survival. Further, they serve as harbingers of future environmental conditions from climate change. Increased weather extremes are also predicted to accompany climate change, and plant species' resilience in the face of these weather events may also factor into their abilities to adapt and survive.

Few studies conducted on effect of atmospheric CO_2 enrichment on specific plant compounds of direct medicinal value. Such studies revealed that under controlled well-watered conditions in a phytotron, tripling of the air's CO_2 content increased dry weight production of medicinal plants of woolly foxglove (*Digitals lanata* EHRH), which produces the cardiac glycoside digoxin that is used in the treatment of cardiac insufficiency by 63% while under water-stressed conditions the CO_2 induced dry weight increase was 83% (Stuhlfouth *et al.* 1987). Results further revealed that a near-tripling of the air's CO_2 concentration led to 75% increase in plant dry weight production/unit land area and 15% increase in digoxin yield/unit dry weight of plant, which combined to produce an actual doubling of total digoxin yield/ha of cultivated land (Stuhlfauth and Fock 1990).

Shifts in phenology

The lifecycles 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). Available evidence indicates that spring emergence has generally been occurring progressively earlier since the 1960s. Such accelerated spring onset has generated noticeable changes in the phenolgical events of many plant species, such as the timing of plants' bud bursts, first leafings, first flowerings, first seed or fruit dispersal, etc. Studies and records indicate that many plants including MAPs have started blooming earlier in response to the earlier occurrences of spring temperatures and weather. It needs further in-depth experimentation and revealing of facts in MAPs.

There is a lot of variability between species, and it is difficult to predict how climate change affects the phenologies of different plants. In one finding it was reported that phenological shifts of medicinal plants were not significantly affecting wild harvesting practices (Cleland *et al*. 2007). It was noted that there was always variations in the timing of the seasons, and collectors of wild medicinal plants are accustomed to adjusting their harvesting schedules accordingly.

Early blooming can be detrimental if an area is prone to cold spells late in the spring season. If a cold spell occured a few days or weeks after early blooming has commenced, then those early buds or fruits froze, potentially killing or affecting the production of some economically useful plants (Zobayed *et al*. 2005). Apple orchards of North Carolina suffered severely from this type of scenario four years back, and the medicinal plant bloodroot (*Sanguinaria canadensis*, Papaveraceae) is also susceptible to frost following early blooming (Shea 2008).

The impact of extreme weather events

Studies, surveys and mounting evidence indicates that extreme weather events such as storms, droughts, and floods have become more prevalent and intense across the globe in recent years (Neilson *et al*. 2005). The frequency and severity of these events are expected to increase in the future as a result of continued warming, having negative effects on human health, infrastructure, and ecosystems. Extreme weather events have been known to affect harvesters' and cultivators' abilities to grow and/or collect medicinal plant species, as reported in recent years.

Extreme weather conditions throughout Europe are impacting medicinal plant production from seeding to harvesting, such as chamomile in Germany and Poland (Pompe *et al*. 2008). In the first year fennel (*Foeniculum vulgare*, Apiaceae) was recorded as having no yield at all in Bulgaria, due to drought conditions during the spring in that country. Due to long and dry summers in Serbia, 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 (Pal *et al*. 2004, Schar *et al*. 2004).

Medicinal plants in other continents have also been impacted by severe weather conditions. Africa's Sahel region experienced one of the most severe droughts of the 20th century. In Africa, medicinal plants of the Sahel include hibiscus (*Hibiscus sabdariffa*, Malvaceae), myrrh (*Commiphora africana*, Burseraceae), frankincense (*Boswellia* spp., Burseraceae), baobab (*Adansonia digitata*, Malvaceae), moringa (*Moringa oleifera*, Moringaceae), and various aloes (*Aloe* spp., Liliaceae). These were affected due to severe drought (Held *et al*. 2005). Future droughts due to climate change could have devastating effects on the region's already suffering ecosystems and harvesting capabilities (Idso *et al*. 2000).

In India, where climate is largely controlled by an annual monsoon, appears to be experiencing increasingly severe and erratic precipitation. A recent study found that the overall amount of monsoon rainfall across central India has remained relatively stable over the past century; however, moderate rainfall events during monsoon have significantly decreased while extreme rainfall events have greatly increased since the early 1980s (Bhardwaj *et al*. 2007). This increase in extreme rainfall events indicates greater potential for future natural disasters. Experts have claimed that the frequency and intensity of flooding has likewise been increasing in India in recent years, and hailstorms have caused huge agricultural losses across areas of India lately. Therefore, such events are to be understood and their impact on MAPs need to be diagnosed.

States like Gujarat and Rajasthan experienced hailstorms and rains in 2006, 2007 and 2008, at times when such events traditionally have not occurred within the past 50 years. Hail and rainstorms have also damaged psyllium (*Plantago ovata*, Plantaginaceae), wheat (*Triticum aestivum*, Poaceae), and cumin (*Cuminum cyminum*, Apiaceae) crops in the area. The destruction of Indian psyllium crops from hail and rainstorms resulted in a smaller than usual annual yield for 2008. Similarly, it was noted that the availability of menthol crystals was affected by heavy monsoon rainfall, which occurred earlier than usual in Northern India and reportedly damaged wild mint (*Mentha arvensis*, Lamiaceae) crops in 2008 (Bhardwaj *et al*. 2007). Such hailstorms and rains are common factors to impact MAPs in general.

Hurricane seasons could also be affected by climate change, although experts do not agree on the possible effects (Dean 2007). Some experts believe that hurricanes will increase in frequency, duration, and intensity; others predict that hurricanes will either not be significantly affected or might even be inhibited by factors related to warming. Regardless, shifts (whether increasing or decreasing) in hurricane activity have the potential to affect the availability of medicinal plants.

Linkages between climate change, plants and livelihoods

Vast population of world's poor depend directly on harvesting non-timber forest products, edible, medicinal and aromatic plants for livelihood and sustenance. Many of these species are under threat from increasing human pressure and loss of natural vegetation accentuated further by climate change. Consequently, the people who depend on them are affected.

Several chemicals derived from medicinal and aromatic plants are historically acknowledged as having pharmaceutical value (Table 1) (Ziska 2005). Even in developed countries, where synthetic drugs dominate, 25% of all prescriptions dispensed from community pharmacies from 1959 through 1980 contained plant extracts or active principles prepared from higher plants. For developing countries, however, the World Health Organization (WHO) reported that more than 3.5 billion people rely on plants as components of their primary health care. In both developed and developing countries, there are a number of economically important pharmaceuticals derived solely from plants (e.g. tobacco), with high economic value.

Table 1 Plant-derived pharmaceutical drugs and their clinical usage. Although many of these drugs are synthesized in developing countries, the World Health Organization estimates that as many as 3.5 billion people still rely on botanical sources for medicines (WHO, 2002). Recent work on atropine and scopolamine indicates that increasing carbon dioxide and/or temperature will alter the concentration and or production of these plant-derived compounds (Ziska 2005)

Drugs	Action/Clinical use	Species
Acetyldigoxin	Cardiotonic	*Digitalis lanata*
Allyl isothiocyanate	Rubefacient	*Brassica nigra*
Atropine	Anticholinergic	*Atropa belladonna*
Berberine	Bacillary dysentery	*Berberis vulgaris*
Codeine	Analgesic, antitussive	*Papaver somniferum*
Danthron	Laxative	*Cassia spp.*
L-Dopa	Anti-Parkinson's	*Mucuna spp.*
Digitoxin	Cardiotonic	*Digitalis purpurea*
Ephedrine	Antihistamine	*Ephedra sinica*
Galanthamine	Cholinesterase inhibitor	*Lycoris squamigera*
Kawain	Tranquilizer	*Piper methysticum*
Lapachol	Anticancer, antitumor	*Tabebuia spp.*
Ouabain	Cardiotonic	*Strophantus gratus*
Quinine	Antimalarial	*Cinchona ledgeriana*
Salicin	Analgesic	*Salix alba*
Taxol	Antitumor	*Taxus baccata/ T. wallichiana*
Vasicine	Cerebral stimulant	*Vinca minor*
Vincristine	Antileukemic agent	*Catharanthus roseus*

An analysis of threat and potential for medicinal plants

The effects of climate change are apparent within ecosystems around the world, including medicinal and aromatic plant populations. Medicinal and Aromatic Plants (MAPs) in Arctic and alpine areas face challenges associated with their rapidly changing environments, and some researchers have raised concerns regarding the possible losses of local plant populations and genetic diversity in those areas. Shifting phenologies and distributions of plants were recorded worldwide, and these factors could ultimately endanger wild MAP species by disrupting synchronized phenologies of interdependent species, exposing some early-blooming MAP species to the dangers of late cold spells, allowing invasives to enter MAP species' habitats and compete for resources, and initiating migratory challenges, among other threats. Extreme weather events already impact the availability and supply of MAPs on the global market, and projected future increases in extreme weather are likely to negatively affect MAP yields even further.

Climate change may not currently represent the biggest threat to MAPs, but can be a greater threat in future decades (Idso *et al*. 2000). Poor people rely on medicinal plants not only as their primary healthcare option, but also as a significant source of income. The potential loss of MAP species from effects of climate change is likely to have major ramifications on the livelihoods of large numbers of vulnerable populations across the world. Further, the problems associated with climate change are likely to be much more difficult to combat than other threats to MAPs. The problems posed by warming temperatures, disrupted seasonal events, extreme weather, and other effects of climate change, on the other hand, cannot be so quickly and easily resolved.

Implication and studies

Climate change is already happening and its effects will certainly increase in the years ahead due to increasing temperature and variability of rainfall. The effects of climate change on medicinal plants, in particular, has not been well-studied and is not fully understood. But, it is evident that with changing climatic conditions plants may up shift, change their structure and habitat etc. Climate change is already causing noticeable effects on lifecycle/distribution of the world's vegetation. As the situation unfolds, climate change may become a more pressing issue for the herbal community, potentially affecting users, harvesters and manufacturers of MAP species.

There is an urgent need to assess the effect of climate change and global warming and particularly effect of elevated CO_2 on medicinal and aromatic plants with a focused approach especially on the accumulation of secondary metabolites (Courtney 2009, Harish *et al.* 2012). The research on medicinal plants is sporadic and insignificant and it is high time that these group of plants as potential sources of neutraceuticals are given due attention. A number of studies are required to be carried out which are as follows: 1. Systematic list of overall RET species of MAPs. 2. Impact on phenology of plants as well as morpho-physiological and biochemical parameters in controlled environments and field. 3. Varietal improvement on biotic and abiotic stress and to assess the genetic integrity of MAP species. 4. Standardization of techniques for long term exposure of high CO_2 and temperature on MAPs and development of innovative techniques to study the impact of CO_2 enrichment and high temperature as in *Eucalyptus camaldulensis* (Kirdmanee *et al.* 1995) and *Rehmannia glutinosa* (Seon *et al.* 1995). 5. Develop strategies for conservation of endangered flora and fauna of medicinal and aromatic value. 6. Organic farming practices of MAPs for conservation of medicinal properties. 7. Compilation of indigenous knowledge of herbal, medicinal and aromatic plants cultivation against elements of climate change. 8. Changes in the composition of secondary metabolites in diverse climatic situations.

The possible effects on MAPs may be particularly significant due to their immense value in traditional system of medicine and for economic usefulness. Although future effects of climate change are uncertain, but this will have an impact on MAPs, and has potential to become much greater threat in future. Potential loss of some MAPs may affect livelihood of large number of people. The problem of warming temperature and disrupted seasonal events also cannot be easily understood, but timely interventions can certainly prevent the loss of biodiversity. The impact of climate change on medicinal plants both cultivated and wild is very significant. The need of the hour is to have a focused research approach especially on the accumulation of secondary metabolites of health significance (Harish *et al.* 2012). The research on medicinal plants with respect to climate change is very sporadic and insignificant in comparison with other commercial crops. It is the high time that, these group of plants should not be left as they are potential sources of bio-molecules and neutraceuticles.

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