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# Analysis of Climate Change Impacts and their Mitigation Strategies on Vegetable Sector in Tropical Islands of Andaman and Nicobar Islands, India

**Shrawan Singh[1*] and Naresh Kumar Bainsla[2]**

[1]*Vegetable Science, Division of Horticulture and Forestry, Central Agricultural Research Institute (CARI), Port Blair- 744101, Andaman and Nicobar Islands, India*

[2]*Plant Breeding, Division of Field Crops, Central Agricultural Research Institute (CARI), Port Blair- 744101, Andaman and Nicobar Islands, India*

[*]**Corresponding author:** Shrawan Singh, Scientist, Vegetable Science, Division of Horticulture and Forestry, Central Agricultural Research Institute (CARI), Port Blair-744101, Andaman and Nicobar Islands, India, Tel: +09474286498; E-mail: singhshrawan@rediffmail.com

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## Abstract

The climate change is real phenomena and it will have impact on productivity and livelihood of primary farming options. Tropical Island regions are among the most vulnerable to this climatic catastrophe which affect local production of foods particularly perishable like vegetables. The phenomena will lead to a situation of high temperature-high humidity-low light with excess or deficit moisture. This change will help pest dynamic and buildup of their population but negatively affect the crop plants. Slight changes in crop factors have large impact on crop physiology and reproductive biology, resultantly larger change in their productivity and profitability. The change in climatic factors modifies genotype × environment interaction for physiological and economic traits by plants. Vegetables are succulent herbs which are more prone to both biotic and abiotic stresses. However, large germplasm and wide range of species and genetic diversity in tropical climate provide an opportunity to develop climate resilient genotypes to minimize the impact and assure economic returns to the farmers. The paper proposes breeding strategies for vegetable crops which could help in climate resilient breeding programme.

**Keywords:** Climate change; Varieties; Andaman Islands; Nutritional security; Abiotic stress

## Introduction

Vegetable crop plants are herbaceous succulents and much prone to abiotic stresses. Most of them are grown in different agro-climatic situations than their evolutionary regions which make the vegetables more vulnerable to adverse climatic factors and associated losses. In tropical regions, the vegetable production always remains on mercy of environmental condition which varies with season and region [1]. The severity of environmental stress imposed on vegetable crops varies with their genotypes and other crop factors. Climate change factored rise in temperatures, reduction in irrigation water or drought situation, occurrence of frequent to prolonged flooding, occurrence of acidity or rise in salinity levels and increase in wind velocity are going to be major limiting factors in sustainable vegetable production in tropical islands [1]. These extremities will also affect microbial population in soil and root rhizosphere, soil health and soil fertility and increase soil erosion in tropics which ultimately reduce crop yield. The increase in decomposition rate of organic sources of nutrients and rapid losses of nutrients through leaching or washing out effect are major concern for vegetable nutrition [2]. Abiotic stresses appearing during vegetable production either can be the primary cause for disorders or they can influence the susceptibility of a harvest product to such disorders. Thus, appropriate changes are desired in crop plant morphology and physiological processes for increasing their adaptability and productivity in changing climatic situation. The abiotic stress also affects the post-harvest life of the vegetables and therefore, it is appropriate to prioritize among the breeding approaches for extending the postharvest life even in abiotic stress situation. This could be through enhancing stress tolerance of edible portion of vegetables through conventional breeding or up-regulating the associated genes and pathway by desirable modifications [3,4]. Such non-conventional breeding efforts are much awaited in tropical crops where climate chane associated factors will certainly reduce the critical time by escalating the speed of vegetable decay.

Further, the productivity of vegetables remains low in tropical islands [1,5] which could be due to genotypic and environmental factors or their interactions. Bray et al. [6] reported yield losses around 50% in vegetable crop primarily due to environmental stresses. In future, the climate associated stress events like high temperature, limited soil moisture and salinity stress will get magnified by climate change impacts [7]. Frequency of extreme events will affect the response of technologies including high yielding genotypes against soil health degradation or changes in disease and pest equilibriums and reproductive biology with modified microclimate.

Tropical islands are rich in plant diversity [8,9] which could be explored for identification of climate resilient genes or genotypes. Further, superior genotypes of vegetables are needed for effective utilization of integrated farming models which are relentlessly being developed for utilization of abundant light and soil moisture in tropics. Here, participatory role of local vegetable growers and knowledge of custodian communities like indigenous tribes about natural vegetable evolution system will speed-up the breeding process of vegetables for developing climate change resilient vegetable varieties. The Andaman and Nicobar Islands, India have been taken as model for analysis because, this geographically isolated region represents true maritime climate with 87% forest cover and significant human and livestock population [10] as well as vulnerability to extreme impact of natural disaster like tsunami [11]. Though, a systematic review was made by de la Peña and Hughes [12] for the improving vegetable productivity in a variable and changing climate for the world and specific attention to tropical continental regions.

But, the tropical island ecosystem has difference in climatic factors and farming practices, therefore, suitable analysis of climate resilient breeding of vegetables was needed for improvement of vegetable sector in tropical islands. Thus, the present paper analysed the research strategies for breeding of climate resilient genotypes in vegetables for tropical island ecosystem.

### Geography of study area

The archipelago of Andaman and Nicobar Islands is constituted of 572 islands in Bay of Bengal in Indian Ocean with geographical area of around 8249 sq km area. It starches between 6° N to 14° N on 92° E to 94° E and grouped into five groups of islands, namely North Andaman, Middle Andaman, South Andaman, Car Nicobar, Nancowry and Campbell Bay (Figure 1). It is located 1100 km from Chennai and 1300 km from Kolkoata, the nearest cities in mainland India. Land use pattern indicates major share under forest (87%) followed by revenue lands (7%), and only 6% for agriculture [10]. The local population is around 3.8 lacs scattered across the 38 inhabited islands and expect their food supply from limited cultivated land area of 50000 ha. Demographically, Andaman and Nicobar Islands have six indigenous tribes namely Nicobari, Jarawa, Onge, Shompen, Sentinal and Great Andamanese and various settler communities from mainland India and nearby countries. These people brought different food cultures which are still maintained but their interactions helped in synthesis of composite culture in life and field activities [13]. The tribal communities have their own nature associated life pattern which will be certainly affected by changing climate but settler farmers are major shareholders in local agriculture, therefore, their livelihood options also have high vulnerability to climate change impacts. Thus, impacts of abiotic stress are varying in nature and intensity from one island to other and also from farmers to farmers which desire mitigation strategies accordingly.

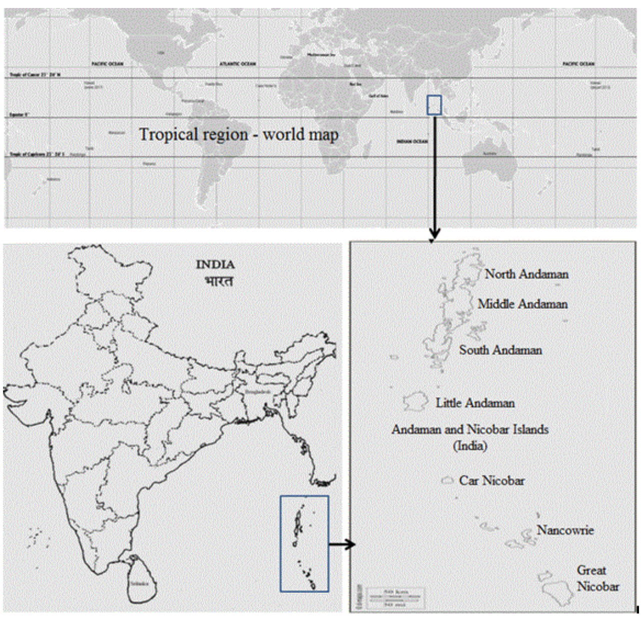


**Figure 1:** Tropical region of the world, India and Andaman and Nicobar Islands.

The islands have tropical humid climate with temperature ranges from 21 to 32°C, maximum in May and minimum in December, high mean value of annual rainfall (3100 mm) which distributed over May to December. Relative humidity remains high during rainy months (>85%) and touch low in February (<70%) [14]. Though, climatic conditions of islands remains favourable for round the year cultivation of tropical vegetables but rain pattern distinguish the crop seasons as rainy season (May to December) and dry season (January to April) [1]. The indigenous vegetables are major contributor in local diets and livelihood during rainy season in islands. The soils of islands are clay and silty in low lands while they are predominantly gravely clay loam, weak, sub angular blocky, friable slightly sticky in uplands soils. The C/ N ratio ranges from 16 to 21 [2], thus, soils of Andaman Islands support cultivation of wide range of vegetables.

## Breeding Strategies

### Breeding for water stress

Water stress is one of the most important abiotic stresses affecting plants where excess water hampers supply of oxygen and essential nutrients to root zone and dilute the osmotic potential of cell and incite roots to secrete stress associated hormones whereas drought stress lead to plant desiccation [3]. Both excess and scarcity of water compromise the plant life and ultimately the yield. Vegetables contain moisture around 90% and any deficiency may cause serious damage to their yield and quality. The climate change impact the availability of drinking and irrigation water [14] and also challenge the vegetable sector in dry months [1]. Mitigation of the impact of flooding on vegetable sector is major challenge to vegetable growers during rainy season in tropical region where high temperature during sunny hours causes rapid wilting and death of plants.

Thus, breeding of genotypes with water stress tolerance for drought period and with high water use efficiency for drought conditions should be planned through targeted participatory approaches in natural conditions per se. For this, the local genetic resources or wild relatives of respective crops from islands can be explored for water logging or moisture stress tolerant genes. For this, the best strategy is to construct and manage the trait specific core groups from local genetic resources with regular enrichment. The islands have indigenous tribes and settler communalities which have association with such crop resources and their traditional knowledge can help in selecting the potential germplasm for targeted breeding. For example, the Solanum torvum is a naturally occurring edible plant species and offers opportunity to use in breeding against both excess and deficit of water. The physiological and genetic mechanisms in such plants should be investigated for their differential responses and use them in other crops. A targeted approach for mining good genes and their transfer in target plant using both genomics and transgenics will be more appropriate. The metabolomics and proteomics can also be used for homologus and orthologustrans-factors and alleles through substrate modification or promoter engineering. For domesticated crops, the best approach will be to screen a large number of available germplasm for moisture stress with negative mass selection method. The selected germplasm can be further utilized by pure line selection or pedigree methods along with systematic crossing programmes based upon the nature of pollination and useful heterosis.

During dry season the availability of water is limited and there are high transpiration losses and commercial species cannot withstand this stress. Therefore, genotypes with vertical leaf venation and lesser surface area, waxy leaves, green stem, stay green, shorter duration, better stomatal position, having escape mechanism can be selected. The conventional breeding approaches can be utilized for such species. However, with the genomics and transgenic approaches can be utilized for transfer of drought desirable genes like Dreb gene cassettes with universal promoters. Such genes can be sourced from local wild germplasm using model approaches.

## Breeding for tolerance to heavy rains

In tropical islands, the high intensity and heavy rains affect crop by severely affect physiological and reproductive processes which are associated with limited light availability, high humidity and greater susceptibility to disease and pest. Thus, breeding strategy should target multi-trait improvement and for that large scale germplasm screening followed by sequential or simultaneous breeding approach should be performed. The allele mining for suitable gene sources and transfer of such genes through conventional or non-conventional methods are options for vegetable improvement. However, due attention is required for endemic wild species of vegetable plants which have been found to be tolerant to heavy rains [9]. Thus, breeding for target stress through population improvement can be deployed for mining better alleles along with markers.

The high relative humidity (85 - 90%) affect reproductive processes like anthesis, dehiscence, pollination and fertilization in vegetable plants [12] particularly in cross pollinated crops [1]. Uptake of nutrients like calcium in tomato and sweet pepper is most affected by excess humidity. Thus, systematic efforts are required to breed the genotypes to sustain extreme humid conditions. As a matter of fact better genotypes with self-pollinated and vegetables which have vegetative portion as economic part shall be ideal choice. For this, the genetic or metabolite pathways of leafy vegetables could be investigated as they perform well in high humidity environments.

## Breeding for efficient use of light

Cloud cover during prolonged rainy season i.e. May to December months reduce light availability to the level of a limiting factor for vegetable cultivation tropical islands, particularly of sun loving in open condition and partial sun loving in intercropping in plantations and affect their yield and quality [15]. Further, the abundant atmospheric moisture absorbs the light and makes it as a limiting factor for crop growth. The situation will increase in coming years due to climate change impact. Thus, breeding of efficient genotypes for light harvesting can be done through genetic changes or modifications in their associated traits like canopy structure, tolerance to pruning and shaping and better translocation system, vertical leaf orientation and better source to sink ratio. Further, the native leafy vegetables like *Eryngium foetidum* L., *Ipomea aquatica* L., *Basella alba* L., *Centella asiatica* Urban. and *Colocasia esculenta* having biomass as principal product and withstand partial to shade conditions. The indirect selection for their further refinement can be done for chlorophyll and accessory pigments. Further, vegetable in Integrated farming system (IFS) is new option for mitigating climate change impact [16], however, breeding of suitable varieties for shade tolerance, suitable for organic or less-chemical farming practices and sufficient raw materials is needed for maximing the crop returns and sustaining the system in tropical islands.

## Breeding for salinity tolerance

Vegetable crops in coastal areas face serious threat from sea water inundation in field or irrigation streams or adverse effect of sea breeze. The natural disaster like Tsunami (2004) damaged around 8000 ha agricultural lands in Andaman and Nicobar Islands only which become unfit for vegetable cultivation [7]. The excess salinity in soil and air affect the ontogeny of the vegetable plants and reduce the productivity. In dry season, high evapo-transpiration causes substantial water loss and leave salt around the plant roots which interferes with nutrient and water uptake [3]. The plants generally try to tackle the problem by various mechanisms such osmotic stress tolerance, salt exclusion and the tolerance of tissue to accumulated salts [17]. The breeding objectives here can include selection for better salt concentration management system. The alien gene transfer from other species having adaptability to salt tolerance which can result in better survival of plants here the classical example is the transfer of *saltolin* rice can be used as model. Tropical islands are also blessed with rich mangrove flora out of which a few species are consumed as vegetables. The genes for salt tolerance can be mined from mangrove plant species and transferred in the commercial species. A few bacterial isolates from the rhizosphere of coastal vegetable plants from Andaman Island and sea water have been found to have excellent salt tolerance capacity (up to 15 $dS^{-mol}$) (Unpublished data). Such bacterial isolates can be targeted for salt tolerance genes for improvement of vegetables like tomato.

## Breeding for temperature extremes

Vegetables are generally sensitive to environmental extremes, and thus high temperatures and limited soil moisture are the major causes of low yields in the tropics [9] and will be further magnified by climate change. Temperature stresses (35-45°C) which frequently occurs in mid-day hours in faulty designed polyhouses in tropical islands causes denaturation and destruct the protoplast to cell death. Such damage are observed in tomato, sweet pepper, palak, lettuce and green onion. High day temperature affect anthesis, dehiscence and fruit setting in tomato and capsicum; increase anti-nutrients and fibre content in leafy vegetables which down grade their quality; affect movement of pollinating agents and also changes stigma-pollen interaction. The rise in above-optimal temperature episodes in coming years due to climate change impact will strongly modify the reproductive processes alone or in conjunction with other environmental factors in vegetables. The size, quality, and shape of storage organs are greatly affected by day and night temperature which affects development of storage portion of tuber crops. The breeding programme for heat tolerance finds place in queue to ensure adequate supply of vegetables in coming decades.

## Breeding for mitigating pest and agro-chemical residues

The vegetable sector in tropical islands has improved a lot by technological interventions [18] but, the progress of vegetable sector has encounters serious problem of lack of resistant varieties to insect and pests [19,20] and resulted in indiscriminate use of chemical pesticides (Swarnam and Velmurgan which contributed in negative impact on health of soil and water bodies in islands [21]. Their report says that 34% vegetable samples of brinjal, okra, green chilli, crucifers, and cucurbits had pesticide residues and 15.3% samples exceeded the prescribed maximum residue limit. Thus, breeding for resistance genotypes against pest and diseases is well accepted but there is scope for finding better genotypes which can mitigate the pesticide residual effect through rapid degradation particularly post-harvest period by virtue of either inherent or induced mechanism. Further, the weed ecology is also one of the major factors for yield losses which are estimated to be very high in leafy vegetables. Use of herbicide has its own limitations in tropical ecology and breeding of weed suppressive or discoursing genotypes in vegetables are suggested. For this, the breeding of genotypes with inherent capacity of smart allelopathy for weed competitiveness is required for drastically reduction in our dependence on chemical use.

## Breeding for efficient nutrient management

The nutrient requirement changes with crop and varieties, soil type and health, climatic situation and management practices. Micronutrients play key role in quality and yield of vegetables and islands soils are found to be deficit in Za, Ca, Cu and Bo which occurs due to washing effect in uplands and leaching out in lowlands. Further, tropical ecology favours rapid loss of chemical nutrients by soil biology or weed factors and also hasten the decomposition rate of organic sources [2,22]. Thus, use of organic agriculture may contribute in sustainability of island ecosystem but it requires suitable crop varieties while present day varieties in most of vegetables are hybrids or input responsive and not much suited for organic concept. Varietal differences for better nutrient uptake from different sources are reported in many species therefore, such genotypes are desired which can sequester higher micronutrients from soil or foliar applications. For this, screening of available gene pools for selection or use in conventional and non-conventional breeding approaches is warranted. The breeding objective for compatibility with useful microorganism for mineralization has not been targeted yet in commercial vegetable crop species. On the other hand selective breeding approaches are required for restoration of problem soils.

## Improvement of indigenous vegetables

Indigenous vegetables have great genetic diversity which sustains them in wide range of stresses including changing climate impact [9]. They are important component in homegardens [23] and contribute significant portion of daily diet and dietary nutrients [24] and helping in reducing micronutrient deficiencies in indigenous tribes [25]. Some of the indigenous vegetables are well adapted to stressful situation like water logging, drought and salinity. In Andaman Islands, indigenous vegetables are inexpensive, easily accessible, and highly nutritious and customarily accepted food and medicines [20]. These crops contribute around 65% of local vegetable market during rainy season and also provide dietary micronutrients and natural antioxidants to tribal and rural communities in islands. The recently initiated systematic breeding on indigenous vegetables has resulted in development high yielding genotypes/varieties of some of the indigenous vegetables (Table 1). Further, perennial vegetables like jackfruit, drumstick, Momordica etc. are well suited to fragile ecosystem [9]. However, there is need to have systematic germplasm surveys and breeding programs for identification/development of multi-stress tolerant crops/varieties to ensure the traditional diets.

| Indigenous vegetables | Variety/genotype | Characteristics |
|---|---|---|
| *Eryngiumfoetidum L.* | CARI Broad Dhaniya | Broad leaves, rich in Fe, Ca and carotenoids and high yield, tolerant to partial shade, drought and water logging conditions, suitable for organic condition |
| *BasellaalbaL.* | CARI Poi Selection | Large, dark green leaves, rich in Fe, Ca, carotenoids, ascorbic acid, high yield, tolerant to partial shade, moisture stress, and water logging conditions and disease and pests |
| *BasellarubaL.* | CARI-Poi Red | Medium size leaves with red veins, rich in Fe, Ca and anthocyanin, tolerant to partial shade, moisture stress, and water logging conditions |
| *MomordicadioicaRoxb* | CARI Kakrol | Attractive green fruits, tolerant to temporary water logged soils |
| *AmaranthusviridisL.* | CARI-AMA-Green | Green, broad leaves, early, high yield, rich in Ca, Fe and carotenoids, tolerant to moisture stress, water logging, suitable for organic cultivation |
| *Amaranthus tricolour L.* | CARI AMA-Red | Purple leaves, early, high yield, rich in Ca, Fe and anthocyanin, tolerant to moisture stress, water logging, suitable for organic cultivation |
| *Hibiscus sabdariffaL.* | CARI HS-1 | Early, high yielding, rich in Fe, Ca, phenolics and carotenoids, tolerant to partial shade, moisture stress, water logging and competent to weeds and low disease and pest attack, suitable for organic cultivation |
| *Centellaasiatica* (L.)Urban | CARI CA-5 | Rich in micronutrients and antioxidants, broad leaves, rapid growing, tolerant to partial shade, water logging and disease and pests, suitable for organic cultivation |
| *IpomeaaquaticaL.* | CARI NB-4 | Fast growing, high yielding, rich in K, Zn, Mg, Fe, Ca, ascorbic acid, tolerant to water logging |
| *Portulacaoleracea* | CARI DB-8 | Rich in Fe, Mn, Mg, phenolics and ascorbic acid, tolerant to moisture stress and water logging condition, partial shade, diseases |

**Table 1:** Climate change resilient improved genotypes of Indigenous vegetables.

## Breeding for protected cultivation

The protected cultivation technology provides favourable climatic conditions and reduces the stress levels for realizing the yield potential of crop plants. This technology has great potential in tropical islands where open cultivation of vegetables is restricted by heavy rains during rainy season [26]. Intense heat and high incidence of ultra-violet rays in dry months reduce the quality of leafy vegetables in open which otherwise very good in protected structures. Further, the land resources are very limited in islands (only 6% of geographical area is under agriculture) [10], therefore, protected cultivation has great scope to achieve self-sufficiency in vegetable sector even with less area. This is also highlighted by the Working group on Carrying Capacity of Andaman and Nicobar Islands (2009). In islands, the yield realization of improved varieties of major vegetables from mainland India are very low (2.7 to 8.6 MT/ha) in open condition. The breeding efforts through introduction and selection process identified promising varieties of different vegetables [1]. But, breeding programme in local conditions is suggested for different protected structures and for different crop seasons [27,28].

## Conclusion

The climate change is now a real challenge to agricultural researchers working across the world. But, its real impact will be in tropical island regions where significant human population will face critical situation for food and nutritional requirements. Scientific efforts developed technologies for production management of various crops through long-term research projects but the real challenge is to provide suitable crop varieties for harnessing the potential of such management practices. The varieties with predominance of adaptive genes for different crop growing conditions could be quite strong approach. The local diversity of vegetables can contribute large in such breeding programme. The location specific breeding approaches are needed for challenging the climate change phenomena in vegetable sector.

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