13 Adaptation Options for Sustainable Production of Cucurbitaceous Vegetable Under Climate Change Situation

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Abstract

Cucurbits are vegetable crops belonging to the family Cucurbitaceae. The family consists of about 118 genera and 825 species. These crops are important sources of livelihood securities for resource poor farmers and can be grown in varied agroclimates ranging from temperate, subtropical, tropical, and arid deserts. Recently, cultivation of crops including cucurbits is confronted with biotic and abiotic stresses caused by global climate change. It is argued that increased CO_2 concentration has beneficial effect on productivities of several crops when studied in isolation. However, under field conditions, the interaction between CO_2 concentration and increased temperature needs to be investigated in details. Pressure of biotic stresses is also likely to increase due to climate change. Wild relatives of cucurbits are also equally impacted by rise in temperatures. It is feared that important species of many crops possessing valuable gene pools will be on the verge of extinction in the near future. The grave ramifications of climate change can be circumvented with a combination of effective climate protection and adaptation measures. Climate protection measures are well established in the Kyoto Protocol to the UN Framework Convention on Climate Change. Possible adaptation measures for cucurbits are weather forecasts, simulation models, breeding short duration varieties, breeding heat- and drought-tolerant varieties, and agronomic manipulations. Developing stress-tolerant/stress-avoiding varieties and appropriate production technologies in cucurbits have a great potential to contribute to food and livelihood security in vulnerable agricultural environments.

13.1 Introduction

Cucurbits are vegetable crops belonging to family Cucurbitaceae. The family consists of about 118 genera and 825 species. There is tremendous genetic diversity within the family, and the range of adaptation for cucurbit species includes

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tropical and subtropical regions, arid deserts, and temperate regions. Cucurbits are consumed in various forms, *i.e*., salad (cucumber, gherkins, long melon), sweet (ash gourd, pointed gourd), pickles (gherkins), deserts (melons), and culinary purpose. Some of them, e.g., bitter gourd, are well known for their unique medicinal properties. In recent years, abortifacient proteins with ribosome-inhibiting properties have been isolated from several cucurbit species, which include momordicin (from *Momordica charantia*), trichosanthin (from *Trichosanthes kirilowii*), and beta-trichosanthin (from *Trichosanthes cucumeroides*). In India, a number of major and minor cucurbits are cultivated in several commercial cropping systems and also as popular kitchen garden crops. Cucurbits share about 5.6% of the total vegetable production in India. Cucurbits are cultivated in all parts of India under varied agroclimatic conditions. Like other crops, cucurbits are also sensitive to climate change and various abiotic stresses.

13.2 Possible Impact of Climate Change on Agriculture Including Vegetables

Despite technological advances like improved varieties, fertilizers, irrigation systems, and biotechnology, weather is still the key determining factor for agricultural productivity. The possible impacts of climate change on agriculture including vegetables are given below.

1. Increase in temperature increases transpiration and in drier regions leads to water stress causing yield reduction. In India, only about 41% area is irrigated and remaining 59% is rainfed. Even if we realize full irrigation potential in the country, nearly 50% area will still remain rainfed. Under such circumstances, increase in temperatures and changes in rainfall patterns are likely to reduce agricultural productivity in rainfed areas.
2. The changed climate will probably lead to a decrease in crop productivity, but with important regional differences (McCarty et al. 2001). In tropical and subtropical regions like in India where the crops are already near the limit of their temperature tolerance, even a slight increase in temperature will result in drastic fall in crop productivity. However, crop productivity is expected to rise slightly in mid- to high latitudes for mean temperature increases of up to 3°C. Coupled with enhanced CO_2 concentration, food productivity in these areas is expected to rise with rise in temperature up to 3°C and fall with further rise in temperature.
3. High temperature increases the rate of development in plants. A short life cycle, though less productive, can be beneficial for escaping drought and frost and late maturing cultivars could benefit from faster development rate. In colder regions, global warming could lead to longer of growth period and optimal assimilation at elevated temperatures.
4. Droughts, floods, tropical cyclones, heavy precipitation, and heat waves will negatively impact agricultural production.
5. Due to melting of glaciers, global sea levels are likely to rise from anywhere between 180 and 590 mm by end of this century leading to loss of land, coastal erosion, flooding, and salinization of ground water. Rapid melting of glaciers in Himalayas could affect availability of water for irrigation especially in the Indo-Gangetic plains as well as neighboring countries.
6. The current fertilizer-use efficiency that ranges between 2% and 50% in India is likely to be reduced further with increasing temperatures. Greater fertilizer use to boost agricultural production will in turn lead to higher emission of greenhouse gases.
7. Small changes in temperature and rainfall will have significant impact on quality of fruits and vegetables with resultant implications in domestic and external trade.
8. Changes in temperature and humidity will also change pest (diseases and insects) population. New and aggressive pests including weeds are likely to invade our crops.

13.3 Adaptation Strategies for Cucurbitaceous Vegetables

Farmers in developing countries including India need adaptive tools to manage the adverse effects of climate change on agricultural productivity and particularly on vegetable production and quality.

Adaptation involves the action that people take in response to or in anticipation of projected or actual changes in climate to reduce adverse impacts and also derive advantage from the opportunities posed by climate change (Parry et al. 2005). However, farmers in our country are usually small-holders and rely heavily on resources available in their farms or within their communities. Thus, technologies that are simple, affordable, and accessible must be developed to increase the resilience of Indian farms. Various management practices are available that have potential to grow vegetables successfully under hot and wet conditions of the lowland tropics. Potential impacts of climate change on agricultural production will depend not only on climate per se, but also on the internal dynamics of agricultural systems, including their ability to adapt to the changes (FAO 2001). Different strategies for climate change adaptation include development of resilient varieties, modifying fertilizer application to enhance nutrient availability to plants, direct delivery of water to roots (drip irrigation), grafting to increase flood and disease tolerance, and use of soil amendments to improve soil fertility and enhance nutrient uptake by plants. Some of the potential adaptive measures for cucurbitaceous vegetables are described below.

13.3.1 Development of Climate-Resilient Varieties

13.3.1.1 Breeding Strategies

Improved germplasm is the most cost-effective option for farmers to meet the challenges of a changing climate. While breeding for high yields, we have been counter selecting genotypes that are water and fertilizer responsive. Superior varieties adapted to a wider range of climatic conditions could result from the discovery of novel genetic variation for tolerance to different biotic and abiotic stresses. Genotypes with improved attributes conditioned by superior combinations of alleles at multiple loci could be identified and advanced. Improved selection techniques are needed to identify these superior genotypes and associated traits, especially from wild and related species that grow in environments which do not support the growth of improved high yielding varieties. Plants native to climates with marked seasonality are able to acclimatize more easily to variable environmental conditions and provide opportunities to identify genes or gene combinations which confer such resilience.

13.3.1.2 Development of Genotypes Resistant/Tolerant to Diseases and Insect Pests

Large gene pool is available in Cucurbitaceae family which can be utilized for the development of pest-tolerant/-resistant varieties or elite breeding lines in cucumber, muskmelon, watermelon, and other important cucurbitaceous vegetable crops. The resistant sources identified in important cucurbits are given Table 13.1.

13.3.1.3 Development of Genotypes Tolerant to Drought

Plants resist water or drought stress in many ways. In slowly developing water deficit, plants may escape drought stress by shortening their life cycle (Chaves and Oliveira 2004). However, the oxidative stress of rapid dehydration is very damaging to the photosynthetic processes, and the capacity for energy dissipation and metabolic protection against reactive oxygen species is the key to survival under drought conditions (Ort 2001; Chaves and Oliveira 2004). Tissue tolerance to severe dehydration is not common in crop plants but is found in species native to extremely dry environments (Ingram and Bartels 1996). Some *Cucurbita* sp. possess some xerophytic characters essential to adapt under water scarcity conditions. This gene pool should be thoroughly studied to isolate drought-tolerant lines in pumpkin and squash. Drought stress is a major environmental factor influencing plant growth and development. *Citrullus colocynthis* is highly drought-tolerant cucurbit species with a deep root system. Differences in gene expression during drought were studied using cDNA-AFLP. Two genes, CcrbohD and CcrbohF, encoding respiratory burst oxidase proteins were cloned using RACE. RT-PCR analysis showed that expression of CcrbohD was rapidly and strongly induced by abiotic stress imposed by PEG, ABA, SA, and JA treatment. CcrbohD has great promise for improving drought tolerance of other cucurbit species.

Table 13.1 Genetic resource in cucurbits resistant to different diseases and insect pests

Crop	Disease/insect pests	Resistance source	References
Cucumber	Powdery mildew	PI 197087, Poinestee, Yomaki, Sparton Salad, PI 197088, *Cucumis ficifolia*, *C. anguria*, *C. dinteri* and *C. sagittatus*, *C. ficifolia* accessions IVf 1801 and PI 280231, *C. anguria* PI 147065, *C. anguria* var. *anguria*, *C. dinteri* PI 374209, and *C. sagittatus* PI 282441	Barnes 1966, Imam and Morkes 1975, Omara 1979, Munger 1979, Lebeda 1984, Choudhary and Fageria 2002, Seshadri US 1990
Cucumber	Downy mildew	Chinese Long and Poinsette	Imam and Morkes 1975, Seshadri 1986, Lower and Edwards 1986
Cucumber	Anthracnose	PI 197087 and PI 175111	Barnes and Epps 1952, Hayja and Peterson 1978 Abul-Hayja et al. 1978, Abul-Hayja and Peterson 1978
Cucumber	CMV	TMG-1, Tokyo Long Green, Chinese Long, Wisconsin and Table Green	Provvidenti 1985, Provvidenti and Hampton 1992
Cucumber	CGMMV	*Cucumis anguria*	Den-Nij 1982
Cucumber	WMV	Table Green and Sarinam	Takeda and Gilbert 1975 & Provvidenti 1985
Musk melon	Powdery mildew	Edisto, PMR-45 and PMR-450; Georgia-47 and C-68; Campo and PMR-6; Arka Rajhans, RM-43 and Pusa Sharbati Campo, Jacumba, Levlita, PM-5 and PMR-6, PI 164323, and PI 180283	Copeland 1957, Bohn and Whitaker 1964, Takada et al. 1975, Norton and Cosper 1985, Choudhury and Sivakami 1972, Khan 1973
Musk melon	Downy mildew	Edisto, Seminole; Buduma Type –1, 2, and 3, Phoontee, Goomuk, Nakkadosa, Ex-2, Annamalai, Edisto, and Harvest Queen; *Cucumis callosus*, WMR-29, MR-l, Punjab Rasila, Cinco, DMDR-l and DMDR-2; Punjab Rasila; EC 163888; Snapmelon collections like SP-l, SP-2, SP-3, KP-2, KP-7, and KP-9	Copeland 1957, Whitner 1960, Sambandam et al. 1979, Zink et al. 1983, Nandpuri 1993, Singh 1996
Musk melon	Fusarium wilt	Delicious-51 and *C. melo* var. *reticulatus*, *indorus*, *chito*, and *flexuosus*	Munger 1954 and Zink et al. 1983
Musk melon	Gummy stem blight	Line PI 140471	Norton and Cosper 1989
Musk melon	CMV	Freeman	Karachi 1975
Musk melon	WMV	PI 414723, B 66–5 and *C. metuliferus*	Webb and Bohn 1962, Webb 1979, Provvidenti and Robinson 1977
Musk melon	Zucchini yellow mosaic virus	PI 161375	Lecoq and Pitrat 1985
Watermelon	Powdery mildew, downy mildew, and anthracnose	Arka Manik	Nath 1973
Watermelon	Anthracnose	Black Stone, Charleston Gray, and Cargo	Robinson and Shail 1981 & Suvanjrakorn and Norton 1980

Watermelon	*Fusarium* wilt	Citron, Calhoun Gray, Sornkylee and Summit, Dixielle, All Sweet, Crimson Sweet, Charleston Gray, and Lousiana Queen	Orton 1911, Elmstrom and Hopkins 1981
Pumpkin and squash	Powdery mildew	*C. moschata*	Sowell and Corley 1969
Pumpkin and squash	Bacterial wilt	*C. pepo*, *C. maxima*, *C. andreana*, and *C. lundellina*	Watterson et al. 1971
Pumpkin and squash	Squash mosaic virus	*C. pepo*, *C. maxima*, and *C. moschata*	Salma and Sill 1968
Pumpkin and squash	WMV and CMV	*C. ecuadorensis* and *C. foetidissima* against	Provvidenti et al. 1978
Cucurbits	Two-spotted spider mite	Cucumber	Gould 1978
Cucurbits	Melon aphid, fruit fly, leaf miner, and red spider mite	Musk melon	Bohn et al. 1972, Khandelwal and Nath 1978, Dhooria et al, 1987

13.3.1.4 Development of Genotypes Tolerant to Salinity

Attempts to improve the salt tolerance of crops through conventional breeding programs have very limited success due to the genetic and physiologic complexity of this trait (Flowers 2004). In addition, tolerance to saline conditions is a developmentally regulated, stage-specific phenomenon; tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad 2004). Success in breeding for salt tolerance requires effective screening methods, existence of genetic variability, and ability to transfer the genes to the species of interest. Screening for salt tolerance in the field is not a recommended practice because of the variable levels of salinity in field soils. Screening should be done in soil-less culture with nutrient solutions of known salt concentrations (Cuartero and Fernandez-Munoz 1999).

13.3.2 Strategies for Water Economy

13.3.2.1 Irrigation Methods

The quality and efficiency of water management determine the yield and quality of vegetable products. The optimum frequency and amount of applied water is a function of climatic and weather conditions, crop species, variety, stage of growth and rooting characteristics, soil water retention capacity and texture, irrigation system, and management factors (Phene et al. 1985). Too much or too little water causes abnormal plant growth, predisposes plants to infection by pathogens, and causes nutritional disorders. If water is scarce and supplies are erratic or variable, then timely irrigation and conservation of soil moisture reserves are the most important agronomic interventions to maintain yields during drought stress. There are several methods of applying irrigation water, and the choice depends on the crop, water availability, soil characteristics, and topography. Application of irrigation water could be through overhead, surface, drip, or subirrigation systems. Surface irrigation methods are utilized in more than 80% of the world's irrigated lands, yet its field level application efficiency is often 40–50% (Von Westarp and Chieng 2004). Drip irrigation delivers water directly to plants through small plastic tubes due to which water losses due to run off and percolation are minimized and water savings of 50–80% are achieved when compared to most traditional surface irrigation methods. Thus, more plants can be irrigated per unit of water by drip irrigation, and with less labor. In Nepal, cauliflower yields using low-cost drip irrigation were not significantly different from those achieved by hand watering; however, the long-term economic and labor benefits were greater using the low-cost drip irrigation (Von Westarp and Chieng 2004). The water-use efficiency in chili pepper was significantly higher in drip irrigation compared to furrow irrigation, with higher efficiencies observed in high delivery rate drip irrigation regimes (AVRDC 2005). For drought-tolerant crop like watermelon, yield differences between furrow and drip irrigated crops were not significantly different; however, the incidence of Fusarium wilt was reduced when a lower drip irrigation rate was used. In general, the use of low-cost drip irrigation is cost-effective and labor-saving and allows more plants to be grown per unit of water, thereby both saving water and increasing farmers' incomes at the same time.

13.3.2.2 Mulching

Various cultural practices such as mulching, the use of shelters, and raised beds are helpful for protection against high temperatures, heavy rains, and flooding. They also conserve soil health in terms of soil moisture and nutrient conservation required for crop production. The organic and inorganic mulches are commonly used for the production of high-valued cucurbitaceous vegetable crops, viz., gynoecious parthenocarpic cucumber hybrid, gynoecious bitter gourd, and summer squash, especially zucchini type either in open or in protected condition. These protective coverings help to reduce evaporation, moderate soil temperature, reduce soil runoff and erosion, protect fruits from direct contact with soil, and minimize weed growth. In addition, the use of organic materials as mulch can help to enhance soil fertility, structure and other soil properties. In India, mulching improved the growth of bottle gourd, round melon, ridge gourd, and sponge gourd compared to the non-mulched controls

Table 13.2 Resistant/tolerant root stocks for cucurbitaceous vegetable crops

Crop	Root stock	Description	References
Bottle Gourd	*Cucurbita moschata* (Duchesne ex. Pow) x *C. maxima* (Duchense ex. Lam.)	Highly resistant to the common pathovars of *F. oxisporum*	Trionfetti Nisini et al. 2002, AVRDC 2009
Cucumber	*L. siceraria*. *C. moschata*, and *Benincasa hispida* (Thunb.)	Resistance to *Phvtophthora capsici* Leonian and *F. oxvsporum*	Wang et al. 2004
Watermelon	*L. siceraria*. *C. moschata*, and *Benincasa hispida* (Thunb.)	Cucumber Mosaic Virus (CMV). Watermelon Mosaic Virus (WMV-11), Zucchini Yellows Mosaic Virus (PRSV). or Zucchini Yellows Mosaic Virus (ZYMV)	Wang et al. 2002
Cucumber	Fig leaf gourd (*Cucurbita ficifolia* Bouché) and bur cucumber (*Sicos angulatus* L.)	Low temperature tolerance	Tachibana 1982, Lee 1994, Ahn et al. 1999, Rivero et al. 2003
Cucumber	Squash rootstock (*Cucurbita moschata* Duch)	Suboptimal temperature tolerance	Shibuya et al. 2007
Watermelon	Shin-tosa-type (*Cucurbita maxima* × *C. moschata*)	Low temperature tolerance	Davis et al. 2008
Watermelon	*Cucurbita maxima* Duchesne × *Cucurbita moschata*	Water-deficit tolerance	Rouphael et al. 2008
Bitter melon	Luffa (*Luffa cylindrica* Roem cv. Cylinder-2)	Waterlogging tolerance	Liao and Lin 1996
Watermelon	*Lagenaria siceraria* cv. SKP a landrace	Waterlogging tolerance	Yetisir et al. 2006, Liao and Lin 1996
Musk melon	Hybrid squash	Salt tolerance	Romero et al. 1997
Cucumber	*Cucurbita* spp.	Tolerance to organic pollutants like drins	Otani and Seike 2007
Cucumber	*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne	Tolerance to organic Pollutants like drins	Otani and Seike 2007

(Pandita and Singh 1992). Yields were the highest when polythene and sarkanda (*Saccharum* spp. and *Canna* spp.) were used as mulching materials. Planting cucurbitaceous vegetables in raised beds can ameliorate the effects of flooding during the rainy season.

13.3.3 Grafting: Tool for Stress Tolerance Under Climate Change Situation

Grafting in fruit trees is normally used to circumvent the problems associated with soil born biotic and abiotic factors. In vegetables including cucurbits, certain root stocks have been identified which possesses tolerance/resistance against such stresses. Grafting on these resistant/tolerant root stocks protects the crop from ill effects of soil born stresses. Some of root stocks identified cucurbits are given in Table 13.2.

13.4 Conclusion

Vulnerability assessment is a key requirement to know the possible impact of climate change and implement adaptation strategies and policies. Several tools have been developed for vulnerability assessment. The important ones are Community-based Risk Screening Tool-Adaptation and Livelihoods (CRiSTAL) developed by the International Institute for Sustainable Development and Assessment and Design for Adaptation to Climate Change: a Prototype Tool (ADAPT) developed by the World Bank. These models screen multiple regions, multiple sectors (agriculture, irrigation, biodiversity, infrastructure, etc.), reveal region-wise risks of climate change, and suggest options for adaptation.

To circumvent losses due to climate change, adaptation measures are essential in affected areas. Some of the possible adaptations for cucurbits under low to moderate climate change are given below.

1. Early warning through value-added weather forecast systems is one of the most important components of adaptation measures. Forecasts on rains, storms, pest appearance, etc., would be highly useful to the farmers to schedule their activities.
2. Breeding new varieties having tolerance to water stress and high temperatures are the best options to fight climate change.
3. Short-season varieties due to their shorter vegetative periods can avoid unfavorable conditions.
4. Adaptation to changed climatic conditions is also possible by adjusting planting dates. In some areas with intense weather change, this may lead to shifting of cropping seasons.
5. Growing mixed varieties and intercropping are likely to reduce vulnerability of a field to climate change as well as incidence of pests.
6. Mulching is helpful in many ways like raising organic content of the soil, improving water holding capacity, reducing runoff and erosion, and making more water available for plants.
7. Micro-irrigation systems like drip irrigation can improve water-use efficiency, reduce fertilizer requirement, and improve productivity as well as quality.

Under severe climatic changes, the farmers are left with only two options, viz., abandonment cultivation of cucurbits or shifting in new areas where these can be grown economically.

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