Research Review

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Improvement in cucurbits for drought and heat stress tolerance — a review

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ABSTRACT

Cucurbits are sensitive to environmental extremes, and thus high temperature and limited soil moisture are major causes of low yield in hot arid region and will be further magnified by climate change. Some abiotic stresses directly reduce growth, while others affect development in a way that reduces or eliminates the crop's value. The response of plants to environmental stresses depends on developmental stages and length and severity of the stress. Plants may respond similarly to avoid one or more stresses through morphological or biochemical mechanisms. Plant breeders need to translate these findings into stress-tolerant varieties by using all tools available that include germplasm screening, marker-assisted selection and genetic transformation besides conventional breeding methods. Therefore, breeding is one of the most efficient approaches for managing abiotic stresses. The genetically complex responses to abiotic stresses are multigenic and thus more difficult to control and engineer. Several abiotic stress tolerant varieties have been developed utilizing conventional breeding approaches. However, rapid progress is required to reduce the gap between potential yield and actual yield in abiotic stress prone environments. Thus, there is an urgent need of breeding climate-smart varieties of cucurbits tolerance to abiotic stresses which have great potential for meeting increased demand. Keeping in view, an attempt has been made to compile the scattered information on concepts, mechanisms and breeding approaches of abiotic stress tolerance in cucurbits.

Key Words: Abiotic stresses, Breeding approaches, Cucurbits, Drought stress, Heat stress

The crops belonging to family Cucurbitaceae are generally known as 'Cucurbits'. The family Cucurbitaceae includes about 118 genera and 825 species, many of which are economically important crops, notably those of the genera are *Cucumis, Cucurbita, Citrullus, Momordica, Lagenaria, Luffa, etc.* They consist of a wide range of vegetables either used for salad (cucumber) or for cooking (all gourds) or as dessert fruit (muskmelon, watermelon) or candied or preserved (ash gourd). Majority of cucurbits are characterized by presence of bitter principle, *i.e.* cucurbitacin at some portions of plant and at some stages of stages of development. Cucurbits are extensively grown in tropical, subtropical and milder zones of India.

They are good source of vitamin (A and C), calcium and iron and play an important role in nutritional security and economic viability of the country. India is the primary centre of several cucurbits like cucumber, ridge gourd, sponge gourd, wax gourd, pointed gourd, ivy gourd, certain species of watermelon and muskmelon (Vavilov and Löve, 1992). A wide range of genetic diversity exists among cucurbits in India and the important crops are listed in Table 1. Among cucurbits, watermelon, muskmelon, round-melon, bottle gourd, ridge gourd, *kachri*, longmelon, snapmelon, several non-dessertic forms of *Cucumis* species, *etc.* are mainly grown in arid regions of India.

Improvement in vegetable crops has traditionally focused on enhancing a plant's ability to resist pests and diseases. That is evidenced by the large number of disease- or insect-resistant/tolerance cultivars released and germplasm used in crop improvement programme. Research on crop resistance or tolerance to abiotic stresses (drought, heat, cold, excess of moisture, salt, pH, *etc.*) has not received much attention (Mou, 2011). On the other hand global warming is widely accepted as fact, although there are still different opinions and modeling results regarding how much the planet will warm up. The changing environments pose serious challenges to global agriculture and place unprece-

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Table 1. Cucurbitaceous crops found in India

Common name	Botanical name	Chromosome number (2n)
Cucumber *(khira)*	*Cucumis sativus*	14
Wild cucumber	*C. hardwickii*	14
Bitter gourd *(karela)*	*Momordica charantia*	22
Sweet gourd *(kakrol)*	*M. cochinchinensis*	28
Spine gourd *(kartoli)*	*M. dioica*	28
Ash gourd *(petha)*	*Benincasa hispida*	24
Ivy gourd *(kundru)*	*Coccinia grandis*	24
Snake gourd *(chichinda)*	*Trichosanthes anguina*	22
Pointed gourd *(parwal)*	*T. dioica*	22
Bottle gourd	*Lagenaria siceraria*	22
Ridge gourd	*Luffa acutangula*	26
Sponge gourd	*L. cylindrica*	26
Satputia	*L. hermaphrodita*	26
Chow-chow *(chayote)*	*Sechium edule*	28
Watermelon	*Citrullus lanatus*	22
Bitter apple *(tumba)*	*C. colocynthis*	22
Muskmelon	*Cucumis melo* L.	24
Snapmelon *(phoot)*	*C. melo var. momordica*	24
Kachri	*C. callosus*	24
Longmelon *(tar kakri)*	*C. melo var. utilissimus*	24
Arya	*C. melo var. chate*	24
Roundmelon *(tinda)*	*Pracitrullus fistulosus*	24
Pumpkin	*Cucurbita moschata*	40
Summer squash	*C. pepo*	40
Winter squash	*C. maxima*	40
Fig leaf gourd	*C. ficifolia*	40
Buffalo gourd	*C. foetidissima*	40

dented pressures on the sustainability of horticulture industry.

The warmer climate threatens the production of many vegetable crops in arid region, especially those summer season crops. The amelioration of crop environments is either impossible or costly. The breeding of varieties resistant to environmental stress is the most effective economical means to improve and stabilize yield under conditions of stress. Crop resistance to various environmental stresses is being improved by traditional and costly breeding methods that involve the stability of yield performance over different environments as a major criterion (Blum and Jordan, 1985).

Forecasts show that warming over the next several decades will take place irrespective of any action taken today. Therefore, development of vegetable crops that can cope with heat, cold, drought and other climate extremes brought by a warming planet may well be the single most important step to adapt to the changes in the future. However, breeding a new variety takes time, often about ten years. The ability to breed such new varieties is undermined by the rapid loss of biological basis of horticulture which is in turn accelerated by climate changes. There is an urgent need to mitigate these abiotic stresses through improvement of vegetable crops. Moreover, vegetables are more sensitive to abiotic stresses as compared to many other crops which cause huge loss in production worldwide. Seeing the large gap that exists between our country and other developed countries, breeders need to take collective action in developing new cultivars better suited to stress environments.

Genetic-environment interaction is to be optimized through research on both breeding and cultural practices. In vegetables, there is a great potential of breeding abiotic stress tolerance cultivars through the contributions of wild relatives (Kumar *et al.*, 2012; Shah *et al.*, 2018). This enormous and difficult task requires tremendous efforts from multiple disciplines. Stress physiology research identifies mechanism of stress tolerance and provides approach, method and traits for screening stress-resistant genotypes. Plant breeders translate these findings into stress-tolerant crop varieties by using all tools available that include germplasm screening, marker-assisted selection, plant transformation and conventional breeding methods.

Several physiological and biochemical processes essential for plant growth and development are significantly affected by abiotic stresses. Cullis (1991) opined that a perceptive of how the interaction of physico-chemical environment reduces plant development and yield will pave the ways for a combination of breeding methods for plant modification to improve tolerance against abiotic stresses. Bhardwaj and Yadav (2012) reported that abiotic stresses modifies photosynthetic rate, relative water content, leaf water potential and stomatal conductance. Ultimately, it destabilizes the membrane structure and permeability, protein structure and function, leading to cell death. However, plant develops various defense mechanisms against stresses at the molecular, cellular and whole plant levels to withstand.

Therefore, comprehensive understanding of abiotic stresses in vegetables is a pre-requisite for plant breeders to evolve tolerant genotype by adopting suitable breeding methodology. There is no single mechanism by which stresses can be alleviated. Recent advances in stress physiology allow embarkation upon breeding programs that employ distinct physiological selection indices for stress tolerance. Using physiological selection indices in breeding work require the definition of the importance and effectiveness of given physiological attributes under stress conditions, the design of a proper selection scheme within the logistic framework of the breeding program and the development of rapid and effective selection techniques. These requirements, the progress made and the future prospects are discussed for tolerance to drought and heat stresses in cucurbits.

TYPES OF ABIOTIC STRESSES

Abiotic stress is defined as the negative impact of non-living factors on living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of variation to adversely affect population performance or individual physiology of organism in a significant way (Vinebrooke *et al.*, 2004). Abiotic stress is the most harmful factor concerning the growth and productivity of crops worldwide. Research has also shown that abiotic stressors are at their most harmful when they occur together, in combinations ofbiotic stress factors. The abiotic stress may be due to moisture (excess or low), temperature (heat or cold), salts, pH (high or low), hail strom, cyclone, high wind velocity, *etc.* In arid parts of the country mainly water stress (drought) and temperature stress (heat) significantly decreased plant growth, development and yield.

Water stress

Among the environmental variables affecting plant growth and development water stress is one of the most important. The water stress may arise either from an insufficient water or drought stress or from excessive water activity or water logging. Moisture stress is one of the greatest environmental factors in reducing yield in the arid and semi-arid tropics. Drought stress is the major abiotic stress for many Indian states *viz.* Rajasthan, parts of Gujarat, Haryana and Andhra Pradesh (Mitra, 2001). Sinha (1986) defined drought as the inadequacy of water availability, including precipitation and soil moisture storage capacity, in quantity and distribution during the life cycle of a crop plant that restricts the expression of full genetic potential of the plant.

Drought is often accompanied by relatively high temperatures, which promote evapo-transpiration and affects photosynthetic kinetics, thus intensifying the effects of drought and further reducing crop yields (Mir *et al.*, 2012). Earlier researchers, Blum and Jordan (1985), Blum (2005 & 2009) and Kumar *et al.* (2012)also reviewed the information on concepts, genetics and breeding approaches of drought tolerance in vegetable crops.

Drought Tolerance

Drought is a sustained period of time without significant rainfall. However, cucurbits being warm season crops which are mainly grown during summer season and require irrigations at critical stages, *viz.* germination, vegetative phase, flowering stage and fruiting stages. At genetic level, the adaptive mechanisms by which plants survive drought collectively referred to drought tolerance (Jones *et al.*, 1980). Leonardis *et al.* (2012) grouped the drought response mechanism into the following three categories (Fig. 1). However, crop plants make use of more than one mechanism at a time to tolerate drought.

i. ***Drought escape:*** The ability of a crop plant to complete its life cycle before development of serious oil and plant water deficits is called as drought escape. This mechanism involves rapid phenol logical development i.e. early flowering and maturity, variation in duration of growth period depending on the extent of water scarcity.
ii. ***Drought avoidance:*** Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture. This mechanism is associated with physiological

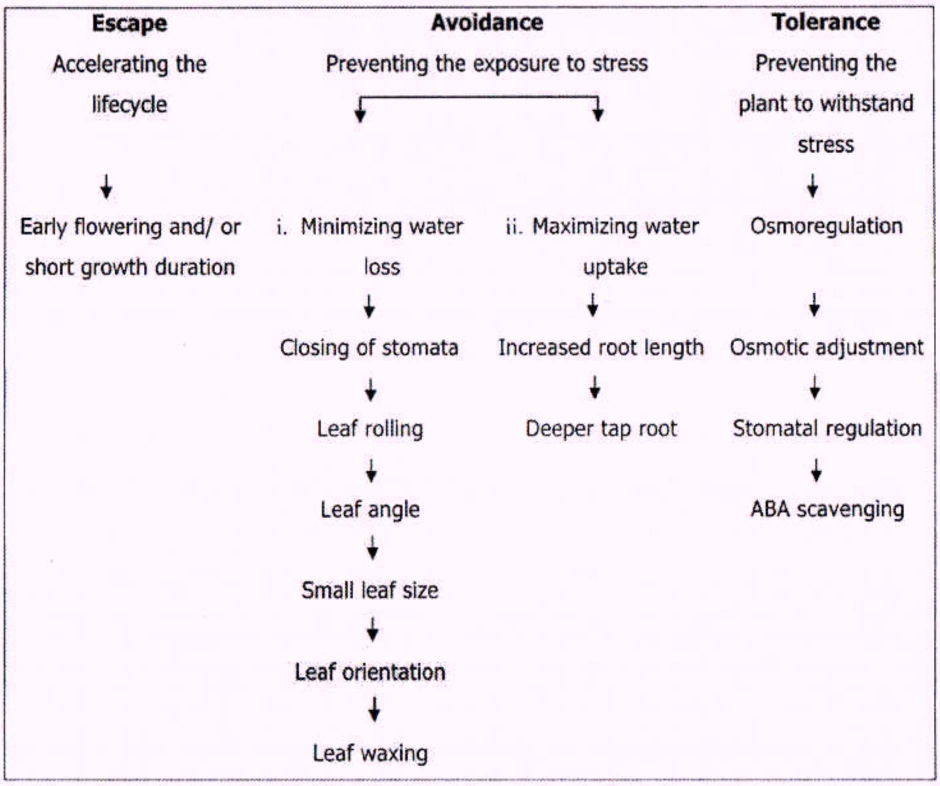

Fig. 1: Response mechanism of drought stress

whole-plant mechanisms such as canopy tolerance and leaf area reduction (which decrease radiation, adsorption and transpiration), stomatal closure, cuticular wax formation, adjustments of sink-source relationships through altering root depth and density, root hair development and root hydraulic conductance.

iii. ***Drought tolerance:*** The ability of a plant to produce its economic product with minimum loss under water deficit environment in relation to the water-constraint-free management is referred as drought tolerance (Mitra, 2001). Under drought condition, plants survive through a balancing act between maintenance of turgor with reduction of water loss. Drought tolerance mechanisms are balancing of turgor through osmotic adjustment (solute accumulation in cell), increase inelasticity in cell but decrease in cell size and desiccation tolerance by protoplasmic tolerance.

The drought tolerance mechanisms conferred by reducing water loss(such as stomatal closure and reduced leaf area) usually result in reduction of assimilation of carbon dioxide (Mitra, 2001). Drought tolerance can be increased through osmotic adjustment by maintaining plant turgor, but the increased solute concentration responsible for osmotic adjustment may have detrimental effect in addition to energy requirement for osmotic regulation. Therefore, crop adaptations to drought may be established through a balance between escape, avoidance and tolerance while maintaining adequate productivity. The source of drought tolerance may be cultivated varieties, landraces, relative wild species or introduced by genetic engineering. The potential sources of drought tolerance species and genotypes of cucurbits have been identified by More and Samadia (2008), More (2010), Choudhary and Sharma (2014) and Saroj (2017) and given in Table 2.

The other non-dessertic forms of Cucumis species like Banga, Kakdi, Mathkachra, etc. are naturally occurring in arid region are tolerant to drought.The success of any improvement programme of drought tolerance depends on selection criteria of germplasm therefore; it should be based on the following criteria.

- It should be easy to estimate/ score.
- It should have high (or at least moderate) heritability.
- A large genetic variability should exist for the trait.
- It should exhibit a significant association with drought (or the desired stress) tolerance.

Table 2. Drought tolerant genotypes/ species of cucurbits

Crop	Drought tolerant genotypes/ species	References
Kachri (*Cucumismelo* var. *callosus*)	AHK-119, AHK-200	Pandey *et al.*, 2011; Kusvuran, 2012 and Saroj, 2017
Snapmelon (*Cucumismelo* var. *momordica*)	VRSM-58, AHS-10, AHS-82	
Arya (*Cucumismelo* var. *chate*)	*Arya*	
Mateera / Watermelon	AHW-65, Thar Manak *Citrullus colocynthis* (L.) Schrad.	More and Khan, 2009 Dane and Liu, 2007

- It should exhibit a significant association with yield under stress.

Screening for drought tolerance

The diversity among the genotypes may serve as primary source for screening against drought stress. Drought tolerance is the interactive result of diverse morphological, physiological and biochemical traits and thus, these components could be used as strong selection criteria to screen out appropriate plant ideo type. Traditionally, plant breeders have addressed the problem of environmental stress by selecting for suitability of performance over a series of environmental conditions using extensive testing and biometrical approaches (Blum, 1988). Water stress, mostly at critical period of growth may drastically reduce productivity and quality of vegetables. Singh and Sarkar (1991) stated that a combination of different traits of direct relevance, rather than a single trait, should be used as selection criteria for drought stress. The screening procedure for drought tolerance is given in Table 3 and critical stages of drought stress and its impact in cucurbits is given in Table 4.

Table 3. Screening procedure for drought tolerance

Instruments/ techniques used	Purpose of screening
Infrared thermometry	Efficient water uptake (Blum *et al.*, 1982).
Banding herbicide metribuzin at a certain depth of soil, and use of iodine-131 and hydroponic culture under stress of 15 bar	Root growth (Robertson *et al.*, 1985).
Adaptation of psychometric procedure	Evaluation of osmotic (Morgan, 1983).
Diffusion porometry technique	Leaf water conductance (Gay, 1986).
Mini-rhizotron technique	Root penetration, distribution and density in the field (Bohm, 1974).
Infrared aerial photography	Dehydration postponement (Blum *et al.*, 1978).
Carbon isotope discrimination	Increased water-use efficiency (Farquhar and Richards, 1984).
Drought index measurement	Total yield and number of fruits (Ndunguru *et al.*, 1995).
Visual scoring or measurement	Maturity, leaf molding, leaf length, angle, orientation, root morphology and other morphological characters (Mitra, 2001).

Table 4. Critical stages of drought stress and its impact on vegetable crops

Crop	Critical stages for irrigation	Impact of water stress
Cucumber	Flowering as well as throughout fruit development	Deformed and non-viable pollen grains, bitterness and deformity in fruits, poorseed viability
Melons	Flowering and evenly throughout fruit development	Poor fruit quality in muskmelon due to decrease in TSS, reducing sugar and ascorbic acid, increase nitrate content in watermelon fruit, poor seed viability.
Summer squash	Bud development and flowering	Deformed and non-viable pollen grains, misshapen fruits.

BREEDING APPROACHES FOR DROUGHT TOLERANCE

The coined slogan 'more crop per drop' (Kijne *et al.*, 2003) as a target for crop improvement in water-limited environments emerged in recent years in the press and among research administrators and sponsors. It is a very catchy slogan indeed, but also a misleading one. It does not serve well the cause of breeding for water-limited environments, especially rain fed conditions. It led breeders to believe that crop production under water-limited conditions can be genetically improved by increasing plant production per given amount of water used by the crop. A misconception also developed that improved water-use efficiency (WUE) is synonymous with drought resistance and high yield under drought stress. It is possible to achieve 'more crop per drop' by certain crop and soil management practices (*e.g.* plant nutrition).

To develop a drought tolerance variety, the breeding methodology to be applied is the same as for other traits improvement programmes *viz.* recurrent selection for cross-pollinated crops. Conversely, if transfer of few drought tolerance traits to a high-yielding genotype is the aim, then back cross method is adopted (Yunus and Paroda, 1982). There is no single trait that plant breeders can use to improve productivity of a given crop under drought stress. Hence, alternative potential systematic approach is to pyramid a number of traits in one genotype which can be helpful for the improvement for its drought tolerance.

Some of the key traits for breeding for drought tolerance [*e.g.* phenology, rapid establishment, early vigor, root density and depths, low and high temperature tolerance, 13C discritunation (a measure of the extent to which photosynthesis is maintained while stomatal conductance decreases), root conductance, osmo regulation, low stomatal conductance, leaf posture, reflectance and duration, and sugar accumulation in stems to support later growth of yield components] are important traits for breeding point of view. However, priority should be given to those traits which can maintain stability of yield in addition to overall yield (Parry *et al.*, 2005).

Therefore, for the evolvement of an improved drought tolerant high yielding variety, it is necessary that the variety should have short life span (drought escape), well-developed root system, high stomatal tolerance, high water use efficiency (drought avoidance), and increased and stabilized yield during water stress period (drought tolerance). Although, a number of crop cultivars tolerant to drought stress have been developed through this method, this approach has been partly successful because it requires large investments in land, labour and capital to screen a large number of progenies and variability in stress occurrence in the target environment (Athar and Ashraf, 2009). The following breeding approaches have been proposed by various researches.

i. ***Breeding under optimum (irrigated) condition:*** This approach is used where the maximum genetic potential of yield is expected to be realized in optimum condition with a high positive association for performance in optimum and stress conditions (Johnson and Frey, 1967). The basic philosophy of this approach is that where a genotype performs better under optimum level will also yield comparatively well in drought stress condition. Often genotype x environment (G x E) interaction may restrict the performance of high-yielding genotype under drought condition.
ii. ***Breeding under actual drought condition:*** In first approach G × E interaction restrict the performance of high-yielding genotype under drought condition, therefore, breeding of high yielding genotypes under actual drought condition has been recommended (Hurd, 1971). However, relative expression of optimum genetic potential in the two extreme conditions may not always fit good for most of the traits. The desired goal to develop high yielding drought-tolerant genotype may be achieved through simultaneous selection in non-stress environment for yield and in drought condition for stability. Moreover, major drawback of this approach is that the intensity of drought is vastly variable from year to year and as a consequence environmental selection pressure on breeding materials changes drastically from generation to generation. This situation is compounded with lower heritability and makes the breeding activities lower and complicated (Roy and Murty, 1970).
iii. ***Integration of breeding methods:*** An alternative strategy to the above two approaches would be to improve drought tolerance in high yielding genotypes through integration of breeding methods based on morphological and physiological mechanisms of drought tolerance. Improving the yield potential of an already tolerant genotype may be a more promising approach, provided there is genetic diversity in such material (Bidinger *et al.*, 1995). Evolving a high-yielding potential variety along with drought stress through conventional breeding is usually carried out either through stability analysis to evaluate the response of the components of yield to stress or by incorporating traits that contribute directly, or indirectly, to yield stability.

Table 5. Response of physiological traits to drought conditions

Trait	Effects relevant for yield	Modulation under stress
Stomatal conductance/ leaf temperature	More/less rapid water consumption. Leaf temperature reflects the evaporation and hence is a function of stomatal conductance.	Stomatal tolerance increases under stress (Lawlor and Cornic, 2002).
Photosynthetic capacity	Modulation of concentration of Calvincycle enzymes and elements of the light reactions.	Reduction under stress (Lawlor and Cornic, 2002).
Single plant leaf area	Plant size and related productivity.	Reduced under stress (wilting, senescence, abscission) (Walter and Shurr, 2005).
Rooting depth	Higher/lower tapping of soil water resources.	Reduced total mass but increased root/shoot ratio, growth into wetsoil layers, re-growth on stress release (Sharp *et al.*, 2004).
Photosynthetic pathway	C3/C4/CAM, higher WUE and greater heat tolerance of C4 and CAM.	–
Osmotic adjustment	Accumulation of solutes: ions, sugars, poly-sugars, amino acids, glycine betaine.	Slow response to water potential (Serraj and Sinclair, 2002).
Membrane composition	Increased membrane stability and changesin aquaporine function.	Regulation in response to water potential changes (Tyerman *et al.*, 2002).
Accumulation of stress-related proteins	Involved in the protection of cellular structure and protein activities.	Accumulated under stress conditions (Ramanjulu and Bartels, 2002).

Utilization of available genetic variation at inter-specific, intra-specific and intra-varietal levels is of prime importance for selection and breeding for enhanced tolerance to any kind of stress (Serraj *et al.*, 2005). Several selection indices based on anatomic, physiological and biochemical criteria for breeding drought tolerant varieties are being employed *e.g.*, seed yield, harvest index, shoot fresh and dry weight, leaf water potential, osmotic adjustment, accumulation of compatible solutes, water use efficiency, stomatal conductance, chlorophyll fluorescence (Neumann, 2008) and therefore strategy for developing elite material against drought is basically inclined towards the physiogenetic approach. The response of various physiological traits to drought conditions is given in Table 5.

Heat tolerance

The global climate will witness an increase of 2-4°C temperature at the end of 21st century (IPCC, 2007). More importantly, the predictions based on global climate model analysis suggest that the tropical and subtropical regions of the world will be the worst sufferer from the forthcoming disaster of heat stress (Battisti and Naylor, 2009).Temperature is basic to life processes, which increases with temperature within a limited range. Abnormally high temperature may cause disruptions in normal physiological and metabolic processes. The temperature stress may affect cell growth, cell wall synthesis, hormonal relationships, protein synthesis, stomatal opening (respiration) and carbon dioxide assimilation (photosynthesis). Similarly, when the temperature goes below a threshold, which is often close to zero, life processes are disturbed enough to cause injury and death in sensitive genotypes.

Cucurbits require warm conditions for growth and development. However, at high temperature (38-45°C), growth at 2-4 leaf stage may be slowed and leaf margins may appear yellow depending on the species, cultivars, length of exposure and other environmental factors. An extremely high temperature (42-45°C), young leaves may appear light green to yellowish after relatively short exposures (24-48 hours). Flowers and fruit abort and sex expression changes from pistillate to staminate if the temperature rises above 38°C for any appreciable time. High temperature during fruit enlargement often results in decreased yield and fruit quality.

Heat stress resistance may be defined as the ability of some genotypes to perform better than others when they are subjected to the same level of heat stress. Generally various mechanisms of heat stress occur in plants are grouped in the following two categories.

Heat avoidance: It is the ability of a genotype to dissipate the radiation energy and thereby avoid a rise in plant temperature to a stress level. The primary mechanism of energy dissipation is transpirational cooling. The other contributory processes include reflective properties of leaves like pubescence, glaucousness, *etc.* This mechanism prevents the exposure of plants to heat stress.

Heat tolerance: Ability of some genotypes to withstand/ perform better than others when their internal temperatures are comparable and in the realm of heat stress is called heat tolerance. It permits the plant to withstand heat stress. Heat tolerance is largely associated with cellular and sub cellular components. Membrane stability, reduced heat sensitivity of photo system II, photosynthetic translocation, stem-reverse mobilization and osmoregulation are the important components involved in heat tolerance.

Breeding for heat tolerance

Increasing severity of high temperature worldwide presents an alarming threat to the humankind. As evident by massive yield losses in various crops, the escalating adverse impacts of heat stress are putting the global food as well as nutritional security at great risk. The genetic structure of heat tolerance is complex which offers a great challenge to breeders (Blum, 1988). It is further exacerbated by the presence of large magnitude of G x E and epistatic interactions. Breeding a vegetable crop for adaptation to a temperature regime that is higher than the recognized optimum for the species in question is an example of breeding for abiotic stress tolerance. Before embarking on a project to breed for such stress tolerance, there are several critical considerations or questions which must be addressed (Farnham, and Bjorkman, 2011) as mentioned below:

- What is the effect of the abiotic stress on the crop to be improved?
- What will be the conditions of the selection environment?
- What germplasm is available that contains the necessary genetic variation to initiate improvement?
- What breeding scheme will be used to facilitate improvement?
- What will be the specific goals of the breeding effort?

Cucurbits being warm season crops are mainly cultivated during summer season in arid regions, where during April to June the environmental temperature increases upto 42°C and goes beyond 45°C which drastically reduced the yield of cucurbits. The adverse effects of high temperature on cucurbits in arid region comprised of wilting of plants due to high rate of transpiration, sun scorching, more number of staminate flowers, improper pollination due to decreased population of honey bees, drying of ovary, fruit cracking, high incidence of mosaic disease, etc. which leads to low yield of poor quality.

Therefore, improvement of cucurbitaceous crops for heat tolerance is one of the priority areas of research. The selection of environment is one of the crucial factor while improvement of any crop for heat tolerance. Singh (2012) advocated four types of environment for screening of heat tolerance genotypes *viz.*, normal field environment, abnormal field environment, programmed environment and in vitro environment. The natural field environment is the simplest and the cheapest to use. But its effectiveness depends mainly on repeatability of the heat stress profile over years, and on the nature of heat tolerance being selected for.

At several locations normal field environment does not provide suitable heat stress conditions, 'abnormal' field environment available at certain locations or during the off-season may be used. Programmed environment is available in either growth chambers or greenhouses. Usually, it is desirable to avoid water stress during evaluation of heat tolerance. Under standings of selection criteria for heat tolerance are determined in terms of several features. Singh (2012) described the following selection criteria for improvement of crops against heat tolerance (Table 6).

Table 6. Different selection criteria for heat tolerance in plants

Characteristic	Measured as	Usefulness as selection criterion
Germination	Per cent germination under heat stress	Useful when crop faces heat stress at germination.
Growth during heat stress	Yield, biomass	Almost always used selection criterion.
Membrane stability	Solute leakage (conductivity test)	Reasonable correlation (r=-0.7) with yield under heat stress.
Photosynthesis sensitivity	Chlorophyll fluorescence at 685 nm	Becoming increasingly important; difficult to assay and especially interpret.
Recovery after heat stress	Yield, biomass, etc.	Used whenever relevant for the target environment.
Sensitivity of reproductive phase	Pollen fertility, flower/ fruit/ seed production	Useful selection criterion; accounted for in selection based on yield under heat stress.

Table 7. High temperature tolerant varieties of cucurbits developed at ICAR-CIAH, Bikaner

Crop	Varieties
Kachri (Cucumis melo var. callosus)	AHK-119, AHK-200
Snapmelon (*Cucumismelo* var. *momordica*)	AHS-10, AHS-82
Bottle gourd *(Lagenaria siceraria)*	Thar Samridhi
Ridge gourd *(Luffa acutangula)*	Thar Karni
Sponge gourd *(Luffa cylindrica)*	Thar Tapish
Longmelon/ *kakdi* (*Cucumis melo* var. *utilissimus*)	Thar Sheetal, AHC-2 and AHC-13
Mateera (Citrullus lanatus)	AHW-19, AHW-65, Thar Manak

The different approaches of improvement for heat stress in different crops have also been advocated by Blum and Jordan (1985) and Jha *et al.* (2014).The conventional crop breeding schemes relying solely on selection and intermating have unintentionally resulted in paucity in the genetic variation especially for economically important traits that underwent domestication/selection (Gur and Zamir, 2004; McCouch, 2004). Intrinsically, plants respond to high temperature stress by triggering a cascade of events and adapt by switching on numerous stress-responsive genes. However, the complex and poorly understood mechanism of heat tolerance limited access to the precise phenotyping techniques, and above all, the substantial G × E effects offer major bottlenecks to the progress of breeding for improving heat tolerance.

Therefore, accelerating crop improvement demands an extensive search for genetic variability in cultivated as well as in wild species. In the context, heat-tolerant gene(s)/QTLs and the component traits conferring heat tolerance must be explored thoroughly within the entire gene pool, especially targeting the non-adapted and underutilized crop wild relatives and the landraces (Lee, 1998; Fernie *et al.*, 2006). Thus, the progressive tailoring of the heat-tolerant genotypes demands a rational integration of molecular breeding, functional genomics and transgenic technologies reinforced with the next-generation phenomics facilities.

The hot arid region is endowed with vast genetic diversity of several local landraces of cucurbitaceous crops like *Kachri* (*Cucumismelo* var. *callosus*), *snapmelon* (*Cucumismelo* var. *momordica*), *Mateera (Citrulluslanatus),* *Tumba (Citrulluscolocynthis)* and several non-dessertic forms of *Cucumis* species *viz., Banga, Kakdi, Mathkachra, etc.* which are tolerant to heat stress (More and Samadia, 2008; More and Khan, 2009). Keeping 'yield' as the principal criterion, serious breeding efforts were made at ICAR-CIAH, Bikaner to develop high-yielding cultivars in most of the cucurbits grown in arid region. The institute is maintaining large number of germplasm of native cucurbits (More, 2010; Saroj, 2017) and is being utilized as source of heat tolerance in breeding programmes on heat stress.

The breeding methods comprised of selection among the available germplasm and recurrent selection. Intra-specific hybridization in *Cucumismelo* group followed by selection in succeeding segregating generations for yield, quality and heat tolerance could be utilized. The systematic breeding programmes resulted in identification and development of high temperature tolerant varieties from available germplasm of cucurbits with moderate yield potential through selection under normal field conditions (More, 2010; Saroj, 2017; Choudhary *et al.*, 2018) as given in Table 7.

Future thrusts

- Priority for collection of wild relatives and under exploited genetic resources.
- Introduction of targeted germplasm for crop improvement.
- Identification of stress tolerant germplasm of vegetables.
- Evaluation of germplasm for yield, quality and tolerance to abiotic stresses.
- Registration of germplasm, breeding lines and parental lines.

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