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Impact of Climate Change on Vegetable Crops: A Scientific Review

Harsh Pathania[1]*, Dr. Santosh Kumari[2], Abika Chauhan[1], Akshita Sharma[1]

[1]M.Sc. Student, Department of Vegetable Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, HP, India

[2]Senior Scientist, Department of Vegetable Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, HP, India

*Corresponding author: pathaniaharsh003@gmail.com

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Abstract

Vegetable crops occupy a central position in India's food security and farm economy, yet they are among the most climate-sensitive agricultural commodities. Rising temperatures, erratic rainfall, elevated atmospheric CO_2 and more frequent extreme weather events are disrupting crop physiology, reducing yields, altering nutritional quality and intensifying pest and disease pressure. This review synthesizes current evidence on how climate change is affecting vegetable production, both globally and in the Indian context, covering physiological responses, crop-specific vulnerabilities (tomato, potato, cauliflower, leafy greens, cucurbits), nutritional implications and adaptation strategies. Key gaps in India-specific research are also identified. The overall aim is to provide a grounded, practical understanding that can inform research priorities and on-ground decision-making for smallholder vegetable farmers who face disproportionate climate risks.

Keywords: *Climate change, Vegetable crops, Heat stress, Drought, Food security, Adaptation*

1. Introduction

The global climate has already warmed by approximately 1.1°C above pre-industrial levels, with projections of a further 1.5–4.0°C rise by 2100 (IPCC, 2021). In India, 2023 was among the warmest years on record, with rising night-time temperatures, shifting monsoon patterns and more frequent extreme events documented across major vegetable-growing states (IMD, 2023). These trends are not merely meteorological abstractions, instead, they are reshaping when, where and how much vegetables can be grown.

Vegetable crops are inherently more climate-sensitive than cereal crops. Their fast growth cycles, narrow thermal optima and high water demands make them especially vulnerable to variability. India produces over 200 million tonnes of vegetables annually (NHB, 2022) and this sector underpins rural livelihoods and urban nutrition for hundreds of millions. Understanding how climate change is affecting vegetable production, and what can be done about it, is therefore a matter of considerable urgency.

2. Key Climate Stressors Affecting Vegetable Production

2.1 Temperature Rise

Temperature governs germination, photosynthesis, flowering and fruit development in vegetable crops. Photosynthesis in most vegetables peaks between 20–30°C; beyond 35°C, the enzyme *Rubisco* loses efficiency, photorespiration increases and chlorophyll can degrade (Wahid et al., 2007). Crucially, elevated night-time temperatures accelerate respiration, diverting photosynthates away from yield-forming organs and reducing harvest indices. In reproductive terms, temperatures above 32°C during anthesis cause pollen sterility in tomato and pepper, resulting in flower drop and fruit abortion (Peet et al., 1998). For cool-season crops like cauliflower and peas, warming winters prevent adequate vernalization, so edible structures fail to form properly.

2.2 Rainfall Variability and Water Stress

India's monsoon is becoming less predictable: the IMD has documented significant variability in onset timing, spatial distribution and intensity across key vegetable-producing states (IMD, 2023). Drought during the reproductive stage of tomato, brinjal or okra causes flower and fruit drop. Waterlogging from intense rainfall events promotes soil-borne pathogens and root asphyxiation. Pereira (2016) described this double-edged nature of water stress- inadequate and excessive moisture, as one of the most difficult management challenges under climate change.

2.3 Elevated CO_2 and Nutritional Quality

Atmospheric CO_2 has surpassed 420 ppm (NOAA, 2023). While elevated CO_2 can stimulate photosynthesis in C_3 vegetables, it simultaneously dilutes protein, iron, zinc and vitamins in plant tissues. Myers et al. (2014) demonstrated that crops grown under elevated CO_2 in Free Air CO_2 Enrichment (FACE) experiments contained meaningfully lower micronutrient concentrations. Dong et al. (2018) extended this to leafy vegetables, showing reduced B vitamins and nitrate. Heat stress further reduces vitamin C and other antioxidants. For India, where vegetables are often the primary affordable micronutrient source for lower-income households, this nutritional erosion is a serious, under-recognized dimension of climate change.

3. Crop-Specific Vulnerabilities

Table 1 summarizes the documented impacts of climate change on major vegetable crops grown in India.

Vegetable	Key Stressor	Main Effect	Estimated Impact	Reference
Tomato	Heat (>32°C)	Pollen sterility, lycopene loss	5–8% yield loss per °C	Peet et al., 1998
Potato	Heat (>25°C)	Tuber initiation failure	16–28% loss by 2050	Hijmans, 2003
Cauliflower	Warm winters	Poor curd development	40–60% area loss by 2080	Kumar et al., 2012
Leafy greens	Heat, elevated CO_2	Bolting, reduced nutrients	Seasonal loss significant	Dong et al., 2018
Cucurbits	High heat	Sex expression shift	Field-reported loss	Wahid et al., 2007

Table 1. Comparative impact of climate change on major vegetable crops (compiled from reviewed literature).

Tomato is the most studied and among the most vulnerable crops. Lycopene synthesis which is responsible for both colour and nutritional value, is suppressed above 32°C. For potato, Hijmans (2003) projected losses of 16–28% across South Asia by mid-century due to disrupted tuber initiation. In Himachal Pradesh, Kumar et al. (2012) estimated that climatically suitable area for cauliflower could shrink by 40–60% under high-emission scenarios by 2080, a projection with direct implications for mountain farming communities where vegetable cultivation is the primary livelihood. Singh et al. (2010) documented that the sowing window for rabi vegetables in the Indo-Gangetic plains has already narrowed by 10–15 days over the past three decades.

4. Pest and Disease Pressure

Climate change enhances the threat from both pests and pathogens. Warmer temperatures are expanding the range and increasing the reproductive rate of key pests: whiteflies (*Bemisia tabaci*), primary vectors of Tomato Yellow Leaf Curl Virus, thrive under elevated temperatures. Deutsch et al. (2018) projected that global crop losses to insect pests will increase substantially with every degree of warming, with tropical and sub-tropical regions like India facing disproportionately higher impacts.

Fungal and bacterial diseases also benefit from changing conditions. *Phytophthora infestans* (late blight) intensifies under warm and humid conditions increasingly common in the Nilgiris and Himalayan foothills. Bacterial wilt (*Ralstonia solanacearum*) is projected to expand its range northward in India as winter minimum temperatures rise, threatening solanaceous crops in states previously protected by cold winters.

5. Adaptation Strategies

Adaptation to climate change in vegetable production operates across several interconnected levels which are discussed in following sections.

Varietal improvement is the most durable long-term strategy. ICAR-IIVR (Varanasi) has released heat-tolerant lines of tomato and brinjal, and drought-tolerant okra lines are in advanced evaluation (ICAR-IIVR, 2021). Bita and Gerats (2013) identified pollen thermotolerance, membrane stability and antioxidant capacity as key molecular traits for selection under heat stress. Faster incorporation of these traits into farmer-accessible varieties is essential.

Agronomic adjustments offer near-term benefits: adjusted sowing dates to avoid peak heat during anthesis; use of 25–50% shade nets (which have demonstrated 15–20% yield improvement in summer tomato at IARI, New Delhi); mulching to moderate root-zone temperature and conserve moisture; and drip irrigation to optimize water delivery. Protected cultivation in polyhouses, shade-net houses and naturally ventilated greenhouses offers the most direct buffering against external climate variability and has already enabled year-round production in parts of Himachal Pradesh, Maharashtra and Gujarat, though high capital costs remain a barrier for smallholders.

At the policy level, weather-indexed crop insurance products designed specifically for vegetables, dedicated climate-adaptive vegetable research under ICAR, expansion of the National Horticulture Mission to explicitly incorporate climate risk and wider deployment of agro-meteorological advisory services through mobile platforms would make a tangible difference.

6. Conclusion

Climate change is already reshaping vegetable production in India and worldwide and the trajectory will intensify unless proactive adaptation is pursued at scale. The crops most central to India's food security and rural livelihoods such as tomato, cauliflower, potato, leafy greens face documented physiological stress, yield losses and nutritional degradation. The threat is compounded by expanding pest and disease pressure. Yet vegetable crops, by virtue of their short cycles and genetic diversity, are also amenable to rapid varietal improvement and agronomic adjustment. The science is clear on what needs to happen. The urgent need now is for policy investment and institutional will to implement solutions at the farm level, with particular attention to the smallholder farmers who bear the greatest risk and currently have the least support.

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