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Climate Change Effects on Sustainable Vegetable Production in India: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors contributed to the study and reviewing of the manuscript. All authors did the perform by editing of the study. All authors read and approved the final manuscript.

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ABSTRACT

This review explores the complex relationship between sustainable vegetable production and climate change, aiming to identify strategies for harnessing climatic shifts to promote resilience and productivity in the agricultural sector. One of the abundant sources of vitamins and minerals in vegetables contributes significantly to food and nutritional security. Vegetables are extremely vulnerable to erratic climate shifts and highly perishable. This study emphasizes the need for adaptable approaches to address issues caused by altered temperature patterns, erratic precipitation and increased extreme weather occurrences. The review highlights the integration of climate-resilient vegetable crop varieties into implementing innovative technologies like precision farming and greenhouse farming and emphasises the need for a holistic approaches. The importance of institutional support, community involvement and policy frameworks is explored to

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address this complex climate change paradox. By combining existing knowledge, this review provides insights into the numerous strategies required for sustainable vegetable production regarding climate change (Use of climate resilient varieties, Adoption of climate-smart agriculture (CSA) practices, Crop diversification). Consequently, this review article aims to examine the climate change effects on growing vegetables in a sustainable manner as well as its management strategies.

Keywords: Climate change; vegetables; adaption; mitigation.

1. INTRODUCTION

Climate change refers to any change in climate over time, whether due to natural variability or/and as a result of human activity and adaptation to climate change requires that farmers first notice that the climate has changed, and then identify useful adaptations and implement them [1]. In recent decades, Climate change has been a big global concern. Conventional farming operations are under threat from extreme weather events, changed precipitation patterns and rising temperatures, necessitating a paradigm shift towards sustainable agricultural methods in vegetable cultivation. Sustainable vegetable production, characterized by eco-friendly practices, resource efficiency and resilience, stands as a viable solution to reduce the impact of climate change on food security and nutritional security. Climate change has accompanied in an era of uncertainty, making traditional agricultural approaches vulnerable to disruptions. Sustainable vegetable production, embedded in ecological principles, seeks to balance environmental health, economic viability and social well-being. This approach prioritizes using organic and natural inputs, reduces reliance on synthetic chemicals and employs conservation techniques to preserve soil fertility.

However, vegetables are generally sensitive to environmental extremes, and thus high temperatures and limited soil moisture are the major causes of low yields as they greatly affect several physiological and biochemical processes. One key aspect of sustainable vegetable production involves adapting cultivation methods to changing climatic conditions. Variability in temperature and precipitation patterns requires farmers to adopt resilient vegetable varieties that can thrive in diverse environments. Additionally, incorporating precision farming techniques, such as controlled environment agriculture and hydroponics, allows for optimal resource utilization and minimizes the ecological footprint of vegetable cultivation.

Among the issues affecting food security is climate change, which has become increasingly prominent as a worldwide concern. The Intergovernmental Panel on Climate Change (IPCC 2013) states that human activity is to affect the rise in greenhouse gas concentrations since 1750. According to Tans and Keeling [2], the concentration of carbon dioxide (CO_2) in 2017 was 409 parts per million (ppm), which was approximately 40% higher than pre-industrial levels. This has directly impacted the rise in air temperature; research shows that between 1880 and 2012, the average temperature of the atmosphere increased by about 0.85 ºC (IPCC 2013). Therefore, the objective is to examine how climate change impacts sustainable vegetable production and the management strategies used to achieve it.

2. IMPACTS OF CLIMATE CHANGE ON VEGETABLE PRODUCTION

Like other crops, vegetable crops are susceptible to changes in climate. Extreme weather conditions often affect vegetables. Thus, high temperatures are the primary cause of low yields, and climate change will only make the situation unfavourable [3]. Global climate change would reduce the production of vegetable crops, especially because of the unpredictable high temperature spells and erratic rainfall patterns. Yusuf [4] also reported that environmental conditions negatively affect tomato yield. The production of different vegetable crops is expected to be impacted by several factors, including persistently declining weather, climate changes brought on by rising temperatures, uncertain rainfall, increased water demand, and an increase in the incidence of diseases. Rainfall is one of the primary elements impacting crop productivity Adeniyi [5]. Water scarcity has a major effect on the yield and quality of vegetables. Bhardwaj [3] also noted that the yield of vegetables was greatly affected by the drought and one of the crops that is most vulnerable to waterlogging is tomato.Several of the main environmental factors influencing vegetable crop production are reviewed below.

3. TEMPERATURE

Temperature, either by itself or in combination with other environmental parameters, profoundly impacts the tomato vegetative and reproductive processes [6]. Stress from high temperatures messes with the metabolic processes that are essential for plant cells to operate normally. It mostly impacts higher plants photosynthetic processes. The pepper fruit set was reduced by high post-pollination temperatures, suggesting that fertilization is susceptible to high temperature stress. The pistil and stamen remained viable during the pre-anthesis period despite exposure to high temperatures. [7]. The symptoms of tomato fruit set failure at higher temperatures were reported by Hazra et al. [8].

Drought: As succulent products, vegetables usually contain a water content of above 90% [9]. Therefore, it has a major influence on the quantity and quality of vegetables, while drought circumstances significantly lower vegetable yield. Various physiological, biochemical and genetic responses can result from drought stress caused by inadequate rainfall or low soil moisture, which can significantly restrict crop growth [10]. Drought conditions harm the sprouting of potato tubers and the germination of seeds in vegetable crops such as onion and okra [11]. The drought is the cause of tomato flower abscission [12]. Srinivasa Rao and Bhatt [12] reported a yield loss of more than 50% in tomatoes during their reproductive stage has been associated with water stress.

Salinity: Growing vegetablesin soil salinity conditions poses a challenge to vegetable production, especially in irrigated crop regions that produce 40% of global food [13]. The USDA states that while tomato, cucumber, eggplant, pepper and onions are among the key crops that are moderately sensitive to salty soils, onions are sensitive. High evapotranspiration causes significant water loss in hot, dry conditions, leaving salt around plant roots that prevents the plants capacity to absorb water. Salinity builds up Na+ and Cl-concentrations that are toxic to plants, alters K+/Na+ ratios, creates ion-specific stressors and physiologically imposes an initial water deficit because of the comparatively high solute concentrations in the soil [14]. Jones [15] and Cheeseman [16] observed plants that are sensitive to salt stress exhibit a variety of symptoms, including decreased photosynthesis, wilting, tissue necrosis, curling and epinasty of the leaves, abscission of the leaves, respiratory changes, loss of cellular integrity and maybe even plant mortality.

Flooding: Vegetables are produced in the tropics throughout both the rainy and dry seasons. However, productivity is often limited during the wet season due to the excessive moisture caused by heavy rain. The majority of plants, especially tomatoes, are extremely susceptible to flooding, and there is little genetic diversity in this trait. Usually, reduced oxygen in the root zone hinders aerobic processes in vegetables due to flooding. After flooding, tomato plants produce endogenous ethylene, which is detrimental to the plants [17]. The roots create more 1-aminocyclopropane-1-carboxylic acid (ACC), an ethylene precursor when the oxygen content is lower. The rapid development of epinastic growth in tomato leaves, which is a unique response to waterlogging, has been associated with ethylene accumulation [18]. After a short period of flooding at high temperatures, tomato plants usually die and wilt due to the aggravating effects of rising temperatures [19].

Importance of Climate Change Adaptation: Apart from the environment itself, the internal dynamics of agricultural systems, in particular their ability to adjust to the changes, will determine the potential effects of climate change on agricultural production [20].

Enhancing Vegetable Production Systems: When various management strategies are used, vegetables produced in the hot and humid tropical lowlands may yield higher yields. The World Vegetable Center has developed technology to lessen production obstacles including flooding and water scarcity, to lessen the effects of salinity and to ensure that the plants receive the right amount of nutrients. The grafting approach uses soil additives to increase soil fertility enhance plant nutrient uptake and increase flood and disease resistance of plants, direct water supply to roots (drip irrigation) and fertilizer management to optimize nutrient availability to plants [21].

Water-saving irrigation management: The production and quality of vegetable products depend upon efficiency and regular water management. The ideal frequency and quantity of water supply are determined by several parameters, including climate and meteorological conditions, crop species and variety, development stage and rooting properties, soil water retention capacity and texture, irrigation system and management considerations [22]. World Vegetable Center and other organizations developed inexpensive, small-scale drip irrigation techniques to help small-holder farmers in developing countries become more successful and less impoverished. For drought-tolerant crops like watermelon, however, yield differences between furrow- and drip-watered crops were not statistically significant.

Cultural practices that conserve water and protect crops: Crop management practices that help preserve soil moisture and protect crops from heavy rain, extreme heat and flooding include mulching, utilizing raised beds and shelters and minimizing soil erosion. These protective covers minimize runoff and erosion, control soil temperature, minimize evaporation, protectfruits from direct soil contact and prevent weed growth. In terms of the growth of eggplant, okra, bottle gourds, round melon, ridge gourds and sponge gourds, mulching is better performed in India than in the non-mulched controls [23]. Tomato yields have improved as a result of the use of simple transparent plastic rain shelters, which stop waterlogging and rain-detrimental effects on maturing fruits [24]. There is also a decrease in fruit cracking and the quantity of unmarketable fruits.

Improved stress tolerance through grafting: It has been mostly employed to regulate soil-borne pathogens grafting techniques in vegetables, which were initially brought to East Asia in the 1900s and are now widely used in Japan, Korea, and several European nations. Grafting is the process of joining two living plant components the scion and the rootstock to create a single, living plant. Diseases that affect the yield of fruits and vegetables, including cucumber, tomatoes, and eggplant. However, it can provide tolerance to soil-related environmental problems such as salinity, drought, low soil temperature and flooding provided suitable tolerant rootstocks are used. Romero et al. [25] reported that melons grafted onto hybrid squash rootstocks showed higher resilience to salt than non-grafted melons. Rootstocks ability to withstand salt varies widely between species; for example, compared to *Lagenaria siceraria* rootstocks, *Cucurbita* spp. rootstocks are more resistant to salt. [26]. Additionally, grafted plants showed greater resistance to low soil temperatures. Although grafted eggplants on *S. integrifolium x S. melongena* rootstocks performed better than ungrafted plants at cooler temperatures (18^{o}C to 21^{o}C),*Solanum lycopersicum* x *S. habrochaites* rootstocks allow their grafted tomato scions to tolerate low soil temperatures (10^{o}C to 13^{o}C) [27]. Research conducted by the World Vegetable Center (AVRDC) has shown that many eggplant accessions are remarkably resistant to flooding [28].

4. CASE STUDIES IN VEGETABLE CROPS

Potato: INFOCROP-POTATO simulation model [29] was used to estimate potato production for the country without any modifications, assuming that future climate scenarios will not affect the crops existing area under cultivation (1.2 m hectares). The results indicated that at elevated CO_2 levels of 550 ppm and a 1°C temperature rise, potato production will increase by 11.12%. However, future climate scenarios for India suggest that temperatures will likely ascend by 3°C at elevated CO_2 levels of 550 ppm [30], with production declining by 13.72% by 2050. According to the IPCC [30], there will probably be no effect from a 1°C increase in temperature on the 400 ppm of CO2 expected in 2020. High temperatures have an impact on development and potato production declines by 3.16%.

Quality: With a decrease in glycoalkaloid and nitrates and an increase in dry matter and starch, elevated CO_2 improved the quality of tubers. Under high CO_2, almost all of the nutritious elements in tubers tend to decrease and the amount of citric acid also falls, increasing the likelihood of discoloration after cooking. In a pot experiment carried out in a naturally ventilated glasshouse, high temperature (30°C) decreased the total dry matter and tuber production and affected quality by lowering the specific gravity of tubers.

Seed tuber production: Dehaulming vines before the aphid population exceeds a threshold, the seed plot technique aimed to prevent viral disease infection and generate seed tubers in plains during winters during relatively aphid-free periods. Potato aphids arrive two weeks in advance of schedule for every degree Celsius that the mean temperature rises. Furthermore, population increase and the highest temperature and lowest relative humidity have a positive link [31].

Onion: Winter and early summer are the seasons for onion harvesting. Bulb initiation takes place between 10 and 15°C at night and 20 to 25°C during the day. The optimum temperature ranges for bulb development are 25–30°C during the day and 18–20°C at night. Day temperatures of 35–38°C are necessary for maturity. Poor bulb development is caused by high night temperatures during the bulb initiation stage. Bolting occurs when temperatures are too low (less than 10°C) during bulb growth. When bulbs mature in April and May, shrink in bulb size due to excessively high temperatures (~42°C) and these bulbs don't keep well in storage for an extended period. In addition, a productive environment is one with optimal humidity, bright sunshine and moderate rainfall.

Effect of CO_2 and temperature: In onion elevated CO_2 in onions promotes growth without having an overall impact on crop duration. A 30–50% increase in bulb production is expected if CO_2 levels are raised from the current ambient levels to 530 ppm. The duration is shortened by warmer temperatures [32]. Bulb yield generally drops by 3.5–15% with every 1°C increase in average temperature. Up to 60–70% of crops fail during the kharif season due to excessive rainfall and overcast weather.

Quality: Heavy rainfall during August – September onions were spoil and their production and storage quality were decreased by the high temperatures in March and April. In January and February, extremely low temperatures (below 10°C) for longer than a week led to a significant percentage of onion bolting.

Studies on the Response of tropical tuber crops to high temperature: Compared to warmer normal environments, the starch content of cassava tubers is higher by more than 5% in cooler climates at high altitudes (1000 msl). This suggests that temperature plays a major role in determining how high CO_2 affects cassava yield enhancement. Photosynthates can also transition to lignification in response to drought and higher temperatures; further study is necessary because this metabolic shift dramatically reduces starch yield. Consequently, long droughts (more than 30 days) and hot weather (over 33°C) can significantly reduce cassava/sweet potato tuber output and starch content.The impact of elevated CO_2 and high temperature on photosynthesis in sweet potatoes has been well explored. Sweet potato leaves have a temperature-sensitive electron transport system and the photosynthesis-related enzyme Rubisco activase. (>35^{o}C). As the temperature increased to 34 °C and the CO2 content increased to 560 ppm, the rate of photosynthetic activity in sweet potato leaves increased.

Studies on the response of cassava and sweet potato to elevated CO_2: The net photosynthetic rate increased noticeably up to 500 ppm CO2; beyond that, the increase in the PN rate was negligible. When high temperature (33/26^{o}C) and high CO_2 (700 ppm) were combined in cassava, tuber production (plant-1 or ha-1) was higher than when control plants grow at 350 ppm CO_2. In cassava, shoot growth was much greater than tuber growth when high temperature (33/26^{o}C) and high CO_2 (700 ppm) were combined. With a doubling of CO_2, the shoot:root ratio decreased; however, because of the more vigorous shoot growth at high temperatures, the loss was less pronounced [33].

Sweet potato: Sweet potato photosynthetic rate, specific leaf weight, biomass and tuber production, when CO_2 levels were raised to 514 and 666 ppm [34,35]. At 363, 514, and 666 ppm of CO_2, the corresponding tuber yield was 346.9, 388.2, and 395.5 g/plant. According to Bhattacharya et al. [36], 91, 32.35, and 32.99 tonnes/ha. Using the SPOTCOMS model, the impact of rising temperatures on sweet potato tuber yield was simulated [37]. The results showed variable effects depending on temperature range. A rise in temperature by 1°C from 19.24-20.24°C increased the tuber yield by 1.26 tonnes/ha, whereas that from 28.24-29.24°C decreased the yield by 0.12 tonnes/ha.

Quality: Under high CO_2 (675 ppm), the amount of beta-carotene, starch and glucose in sweet potato [38,36].

Cassava: The production of total dry matter, tuber yield and photosynthetic rate all decrease in conditions of water deficiency stress (28–42%). However, it was shown that cassava maintained about 50% of its photosynthetic activity during droughts, making it a better crop choice for hotter climates in the future. There is a great choice of genetic variation in genotypes related to drought tolerance [40].

Quality: Cassava can sustain vegetative growth and biomass at high temperatures (40°C) and enough soil moisture; nevertheless, this will affect the synthesis of starch in tubers and the export of sucrose from leaves. The starch biosynthesis-related enzymes are extremely sensitive to air temperatures over approximately 30°C. Higher altitudes with lower temperatures have been found to have a 3-5% higher starch content in cassava tubers than in warmer plains climates. Therefore, drought and high temperatures (~30°C) can greatly lower tuber production and beta-carotene content.

Other vegetable effects of elevated CO_2: When cucumbers were cultivated at 620 µ mol mol-1 CO_2 as compared to 300 µ mol mol-1 CO_2, a yield increase of 34% was seen [41]. Elevated CO_2 enhanced yield by 24% and 31% in eggplant and tomato, respectively. Disorders in leaf and branch growth transpired, leading to a decrease in the amount of active leaf area. Two onion cultivars had quicker rates of photosynthesis and leaf area expansion during the pre-bulbing stage, increasing bulb yield of 28.9–51.0%. However, the time to bulb maturity was also prolonged due to the increase in CO2 concentration. At IIHR, Bangalore, increased CO_2 (550 ppm) had an impact on the onion variety Arka kalyan general growth and development, resulting in higher dry matter content in the leaves, stem and bulbs.

Elevated CO_2 (550 ppm) affected growth and development in tomato cv. Arka Ashish and resulted in a 24.4% increase in yield. Plant height, the quantity of secondary branches and leaf area were the growth characteristics that were greater at raised levels compared to ambient values during the fruiting stage. In comparison to the ambient level, the accumulation of dry matter in the fruits, leaves and stem was greater at increasing CO_2 levels. At greater CO_2, the rate of photosynthesis increased, but stomatal conductance and transpiration decreased. In comparison to the chamber control, there was a larger fruit production because there were more fruits per plant under enhanced CO_2.

Table 1. Response of sweet potato to temperature changes

Variety	Seasonal mean temperature (°C)		Seasonal mean temperature (°C)	
	19.24	20.24	28.24	29.94
Sree Arun	5.01	6.23	8.2	8.36
Sree Bhadra	4.17	6.45	7.76	7.49
Sree Rethna	7.97	8.25	10.24	9.98
Mean	5.72	6.98	8.73	8.61

Source: Santosh Mithra and Somasundaram, [37]

Table 2. Seasonal variation in temperature

Season	Mean temperature°C			Mean RH (%)	Total rainfall (mm)	Mean weevil population per plant	Tuber damaged (%)
	Max.	Min.	Mean				
Jun-Sep	29.45	23.33	26.39	84.88	1161.7	0.74	44.75
Feb-May	32.58	24.43	28.51	73.0	368.4	1.07	71.0

Rajamma and Pillai, [39]

Table 3. Effect of elevated carbon dioxide on growth and gas exchange characteristics of onion *cv*. Arka kalyan

Characters	Bulb initiation stage		Bulb development stage	
	550 ppm	Ambient	550 ppm	Ambient
Pseudo stem height (cm)	4.6	3.76	13.8	11.0
Number of leaves	0.5	4.2	9.8	9.4
Dry weight of leaf (g)	0.31	0.18	4.58	3.22
Dry weight of stem (g)	0.18	0.05	1.63	0.91
Dry weight of bulb (g)	0.07	0.05	7.84	4.06
Leaf area (cm^2)	100.31	60.02	775.92	564.88
Photosynthesis rate (mol m^{-2} s^{-1})	11.81	9.89	17.78	9.48
Transpiration rate (mm m^{-2} s^{-1})	2.82	3.31	15.30	19.04
Stomatal conductance (mol m^{-2} s^{-1})	0.16	0.22	2.71	4.02

Table 4. Effect of elevated Carbon dioxide on growth and gas exchange characteristics of tomato cv. Arka Ashish is at the fruiting stage

Characters	550 ppm	Ambient (350 ppm)
Plant height (cm)	114	102.5
Number of primary branches	11	12
Number of secondary branches	65.5	47.5
Dry weight of leaf (g)	222.10	110.02
Dry weight of stem (g)	155.38	78.53
Dry weight of bulb (g)	149.26	137.64
Leaf area (cm^2)	1.31	1.28
Photosynthesis rate (mol m^{-2} s^{-1})	27.44	18.15
Transpiration rate (mm m^{-2} s^{-1})	11.87	13.01
Stomatal conductance (mol m^{-2} s^{-1})	0.34	0.48

Elevated temperatures in tomato plants can lead to reduced fruit sets, smaller and inferior fruits, and notable reductions in production [42]. According to Hazra et al. [8], symptoms of tomato fruit set failure at high temperatures include bud drop, abnormal flower development, poor pollen production, dehiscence and viability, ovule abortion and poor viability, decreased carbohydrate availability and other reproductive abnormalities. Tomato lines that can withstand high temperatures are AVRDC CL-5915-206DG2-2-0 and CL 5915-223-21-01. The pepper fruit set was hampered by high post-pollination temperatures, suggesting that fertilization is susceptible to high temperature stress. However, high temperature exposure at the pre-anthesis stage did not impair pistil or stamen viability [7]. Onions undergo bulbing when exposed to photoperiod, which happens quickly at higher temperatures [43]. Low temperatures in cucumbers generally result in more producing female flowers, whereas high temperatures result in the formation of more male flowers [44]. This affects the expression of sex in cucumbers.

5. MANAGEMENT PRACTICES TO MITIGATE AND ADAPT TO CLIMATE CHANGE

5.1 Developing Climate- Resilient Vegetables

More effective selection techniques are needed to identify these superior genotypes and associated traits, especially in closely related wild species that live in environments that are not suitable for the formation of domesticated relatives that are cultivated varieties. Pereira and Chavez [45]) reported Native plants in areas with significant seasonal variations are better able to adjust to changing weather patterns and provide opportunities to identify the genes or gene combinations that confer such resilience.

5.2 Tolerance to High Temperatures

Chinese cabbage and tomatoes are typically suited to hot, humid tropical climates and low-input cropping methods. The World Vegetable Center has played a major role in the development of Chinese cabbage and tomato lines that can withstand heat, as well as the subsequent global distribution of tropical varieties that have been specially suited. Expanding the genetic foundation of heat-tolerant cultivars by crossing them with disease-resistant temperate or winter types is essential to producing high yields [46]. To match the demands of a changing climate, more heat-tolerant cultivars are needed and these cultivars must be able to equal conventional, non-heat-tolerant types yields in non-stressful environments. Usually, only 1% or less of the germplasms or screened lines exhibit significant heat tolerance [47].

5.3 Drought Tolerance and Water-Use Efficiency

Plants have numerous strategies for surviving water or drought stress. Plants may shorten their life cycle to evade drought stress in a slowly increasing water deficit [48]. Accessions of *S.cheesmanii*, *S.chilense*, *S.lycopersicum*, *S.lycopersicum* var. *cerasiforme*, *S.pennellii, S.peruvianum*, and *S.pimpinellifolium* are among the putatively stress tolerant tomato. Germplasm has been collected by the Tomato Genetics Resource Center (TGRC) at the University of California, Davis. Native to dry and semi-arid regions of South America are *S.chilense and S.pennelli*.

5.4 Climate-Proofing through Genomics and Biotechnology

To boost crop productivity in adverse conditions, modern technology will be required to support conventional approaches, which are sometimes inadequate to stop yield losses due to environmental constraints. Over the past ten years, genomics has progressed from whole genome sequencing to the creation of innovative high-throughput genetic and molecular technologies. Gene functions have been determined and comprehended. Because of this, it is now feasible to genetically alter genes related to environmental stress tolerance.

5.5 QTLs and Gene Discovery for Tolerance to Stresses

Plant breeding has been transformed by the use of molecular technology for genetic improvement. The structural and functional characteristics of plant genomes are now better understood because of developments in genetics and genomics. The potential to develop crop plants is increased when we combine fresh insights from genomic research with conventional breeding techniques. Breeding operations may become more efficient through the use of molecular markers as a selection tool, which can reduce environmental variability, facilitate early selection and reduce subsequent population sizes for field testing. Molecular markers make it possible to identify the genes governing quantitative features and efficiently introduce superior alleles from wild species into breeding operations. Consequently, cultivars that are more resilient to stress and produce more would be developed faster, benefiting farmers in underdeveloped nations.

5.6 Engineering Stress Tolerance

Wang et al. [49] reported Environmental stress tolerance is a complex characteristic that is regulated by several genes. Stresses cause changes in the expression patterns of both proteins and RNA. Using microarray technology, about 130 genes that are responsive to drought have been found [50,51,52,53,54].

6. FUTURE STRATEGIES FOR RESEARCH

1. Breeding vegetable hybrids and varieties drought and heat-tolerant types.
2. Compilation and application of indigenous technical knowledge of vegetable production under warm and drought conditions.
3. Develop agronomic strategies for growing in warm climates.
4. Development and validation of vegetable crop models for Indian conditions.
5. Research on the effects of global warming and climate change on vegetable crops.
6. Research on how the dynamics of the pest complex in vegetable crops are affected by climate change and global warming.
7. Accurate forecasting of climate change with increased temporal and spatial resolution.
8. Integrating forecasts with methods of agricultural production to provide workable solutions for maintaining agricultural production.
9. Creation of a database detailing how climate change is affecting agriculture.
10. Creation of models to analyze the dynamics of insect populations and evaluate how climate change is affecting specific regions.

7. CONCLUSION

An adaptive and flexible strategy that takes into account the difficulties presented by changing climatic circumstances is needed to harness climate change for sustainable vegetable production. Climate change and human-caused greenhouse gas emissions have several consequences on agricultural production, but their combined effect is still unknown. To be precise, not all of these impacts and their interactions have been measured yet, especially not all of them globally. Although it makes sense to expect an increase in the mean temperature, the timing and severity of high temperatures may have a greater impact on production. Thus, it makes sense to expect the mean sea level to increase, which could ultimately result in permanent flooding and the loss of agricultural land. Even though they are less predictable, storm surges can substantially affect short-term floods. For most crops, climate change is the cause of long-term crop production decline. Short-term impacts might not be very noticeable. But even in the short term, more climatic variability could cause significant shifts in productivity. By putting these strategies into practice, vegetable production can be increased to mitigate the effects of climate change and promote sustainable food systems.

In conclusion, addressing climate change in the context of sustainable vegetable production requires an all-encompassing and collaborative approach. In the vegetable production industry, resilience can be increased and the negative consequences of climate change can be lessened by combining technological innovation, adaptive strategies, regulatory assistance, and community involvement. The present evaluation underscores the significance of adopting a comprehensive and cohesive strategy to guarantee the enduring viability of vegetable cultivation amidst the evolving climate.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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