The Changing Horticulture Landscape in Uttarakhand in a Warming Climate

AUTHORS

Dr. Debdatta Chakraborty
Research Associate, Climate Trends

Dr. Palak Balyan,
Research Lead, Climate Trends

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ACKNOWLEDGEMENTS

Climate Trends is grateful for the support and cooperation of the faculty at Govind Ballabh Pant University of Agriculture and Technology in this research. The study has been enriched by the technical inputs received from

- **Dr. D.C. Dimri,** Professor & Head, Department of Horticulture
- **Dr. A.K. Singh,** Professor, Department of Horticulture
- **Dr. Asutosh Singh,** Professor, College of Agribusiness Management,
- **Dr. Amardeep Chauhan,** Professor, Department of Agricultural Communication
- **Dr. Ajeet Singh Nain,** Professor and Director Research, Department of Agrometeorology

We thank the farmers, retailers, wholesalers of Udham Singh Nagar and Nainital for their wholehearted participation in the research. We would like to acknowledge the contributions of environmentalist Dr Man Mohan Singh in facilitating our field research. We would like to acknowledge the contributions of our intern Parv Chawla in data collection.

ABOUT CLIMATE TRENDS

Climate Trends is a research-based consulting and capacity building initiative that aims to bring greater focus on issues of environment, climate change and sustainable development. We specialise in developing comprehensive analyses of complex issues to enable effective decision making in the private and public sector.
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Table of Contents

List of Table

List of Figures

Executive Summary

This report examines the impacts of climate change on tropical fruit cultivation in Uttarakhand, a Himalayan state highly vulnerable to climatic shifts. The state, known for its diverse agro-climatic conditions, has seen significant declines in fruit yields due to warming temperatures, erratic rainfall, and extreme weather events.

Key Findings

1. **Climate Impacts on Fruit Cultivation:**
   Fruit crops, particularly perennials, are acutely vulnerable to climate change due to their long growth cycles and dependence on specific climatic cues. Warmer winters, shifting rainfall patterns, and increased frequency of extreme weather events have disrupted flowering, fruit set, and ripening processes, leading to yield reductions.
2. **Declining Fruit Production:**
   Uttarakhand has witnessed a steep decline in both the area under cultivation and the yield of major fruit crops. Between 2016-2023, the area under fruit cultivation dropped by 54%, and total fruit yields declined by 44%. The shift is most apparent in temperate fruit varieties, while tropical fruits such as mango and guava show mixed trends.
3. **Effects of Climate Change on Fruit Production:**
   Extreme heat and rainfall events are wreaking havoc on summer fruits like mango, litchi and guava increasing the quantum of fruit losses through rising incidences of sunburn, fruit cracking, fungal infection etc. Rising temperatures and shifting weather patterns have exacerbated pest infestations, disrupted pollinator activity, and accelerated soil degradation. These factors have further compounded the challenges faced by fruit growers, affecting fruit quality and marketability.
4. **Supply Chain Disruptions:**
   Extreme weather events and temperature fluctuations have reduced the marketability of fruits, rendering them unsuitable for consumption or causing rapid spoilage post-harvest. This has led to increased reliance on imported fruit varieties, straining local supply chains.
5. **Innovations and Adaptation Strategies:**
   Farmers are increasingly adopting climate-resilient practices such as high-density orchards, the introduction of low-chill apple and peach varieties, and shifting to drought-tolerant crops like dragon fruit and kiwi. These adaptations are aimed at mitigating the adverse effects of climate change and ensuring the sustainability of fruit cultivation in the region.

Climate change is reshaping Uttarakhand's horticultural landscape, with significant implications for fruit production and rural livelihoods. While innovative agricultural practices offer pathways for adaptation, the sector's long-term resilience will depend on continued research and strategic planning to combat the ongoing climate challenges.

1. Background

Uttarakhand occupies a central place in fruit cultivation in the Himalayan belt with horticulture and food processing contributing more than 30% to the state's agriculture GDP (NABARD, 2023-24). However, fruit production in the state has plummeted significantly over the last decade. Climate change induced warming, shifting rainfall patterns and recurring disasters have profound implications for the horticulture sector, affecting the productivity of major fruit crops in the state (Rehman et al; 2015).

Based on a field exploration in Udham Singh Nagar and Nainital districts, the report explores how tropical fruit cultivation in Uttarakhand is impacted by and adapting to a warming climate. The report is divided into five sections. The introductory section sets the context and states the rationale of the study. The methodology presents a broad overview of the location of the research and identifies the study population and research instruments used. The subsequent sections summarise the impacts of climate change on production and supply chain of mango, guava and litchi in two districts of Uttarakhand. The report concludes with the adaptation pathways adopted by farmers to cope with climate change in Uttarakhand.

1.1. Why Fruit Cultivation is Vulnerable to Climate Change

Fruit trees have long growth cycles and are perennial. Once planted, perennial crops cannot be easily relocated. If the local climate becomes unsuitable due to warming temperatures, changing precipitation patterns, or increased frequency of extreme weather events, it is not feasible to simply move the tree to a more suitable location (Rehman et al; 2015). This makes them more vulnerable to the localised impacts of climate change than annual crops. Many perennial crops rely on specific seasonal cues, such as temperature and day length, to regulate key life cycle events like dormancy, flowering, and fruiting. Climate change can disrupt these cues (Rehman et al; 2015). Changes in temperature, precipitation patterns, and the frequency of extreme weather events can lead to disruptions in fruit production, quality, and distribution. Floods and storms can create transportation bottlenecks and affect the timely delivery of fruits to markets. Additionally, the variability in production and supply due to climate change has led to price volatility, impacting both producers and consumers (Tchonkouang et al; 2024).

Climate change affects the physiological processes of fruit trees, including flowering, fruit set, and maturation. Temperature is a critical factor in determining the timing of these processes (Malhotra, 2017). Increased temperatures can lead to earlier flowering in many fruit species, which may expose blossoms to late frosts, reducing fruit set and yield (Lobell & Field 2007). Heat can also accelerate the ripening process, leading to smaller fruit sizes and reduced sugar content, affecting both marketability and nutritional value (Cammarano et al., 2012).

Reduced availability of water during critical growth periods resulting from altered precipitation patterns and increased evaporation rates, can further exacerbate these conditions (Challinor et al., 2014). Moreover, the required chilling hours, a period of cold weather necessary for bud break in temperate fruits like apples, peaches, and cherries, are becoming insufficient in many regions due to warming winters (Atkinson et al., 2013).

Conversely, in some regions, climate change may extend the growing season, potentially allowing for multiple harvests or the cultivation of new fruit varieties. However, these potential benefits are often offset by the increased risk of extreme weather events, such as heatwaves, droughts, and floods, which can cause sudden and severe crop losses (Schlenker and Roberts, 2009).

1.2. Declining Fruit Production in the Himalayan State of Uttarakhand

Fruit plantations serve the dual purpose of maintaining forest cover while providing employment and economic benefits to farmers (Sati, 2022). The mountains, lush green valleys and undulating plains in the state with their diverse climatic conditions are ideal for the production of both temperate and subtropical fruits. Temperature ranges from negative to 40 degrees Celsius and average annual rainfall of 1200 mm favours the growth of several fruit cultivars/species across altitudes (Sati 2022). The cold climate of the highlands is particularly favourable for apple cultivation, while the hot winds (Loo) in the *Tarai* and *Bhabar* regions enhance the quality of mangoes. High rainfall during the monsoon and a humid climate year-round further support fruit cultivation in the region (Sati, 2022).

However, despite the favourable agro-climatic conditions, the diversity of fruits, and the suitable landscape for cultivation, the Uttarakhand Himalayas have not achieved notable success in fruit production. The area under fruit cultivation and its yield remain significantly lower compared to that of food grains and vegetables. Furthermore, climatic shifts have led to a decline in both fruit production and productivity (Sati, 2022).

Once a leading producer of pear, peach, plum, and apricot and apples in the country, the yield of major fruit have plummeted significantly in the state in the past seven years, according to the data from the Uttarakhand Horticulture Mission. The decline in yield and area under cultivation of major fruit crops have been stark since 2020. The dip is particularly remarkable for temperate fruits as compared to their tropical counterparts. Changing temperature patterns in the state could partially explain the shifting horticultural production in the state. With warming climate rendering certain fruit varieties less productive, farmers are shifting towards tropical alternatives which are better attuned to the altering climatic conditions.

Table 1: Decline in Area under cultivation and yield of all types of fruit crops in Uttarakhand

	2016-17	2022-23	% decline
Total Area under fruit cultivation in hectares	177323.5	81692.58	54
Total Yield of Fruits in Metric Tonnes	662847.11	369447.3	44

Source: Department of Horticulture, Government of Uttarakhand

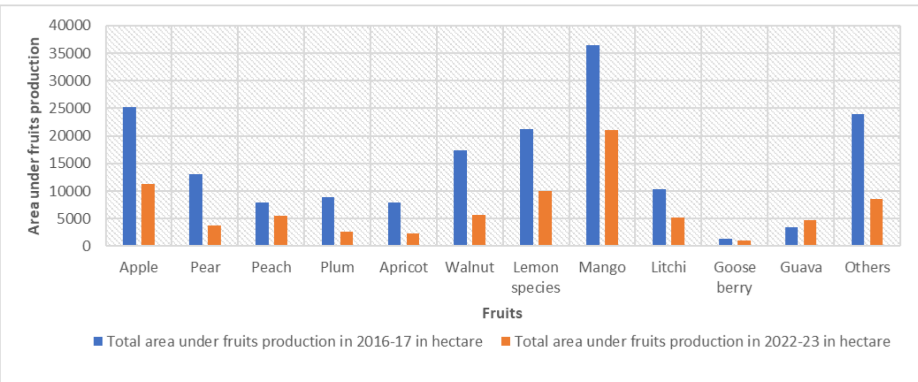


Figure 1: Changes in Area under Different Fruit Cultivation between 2016 and 2023
Source: Department of Horticulture, Government of Uttarakhand

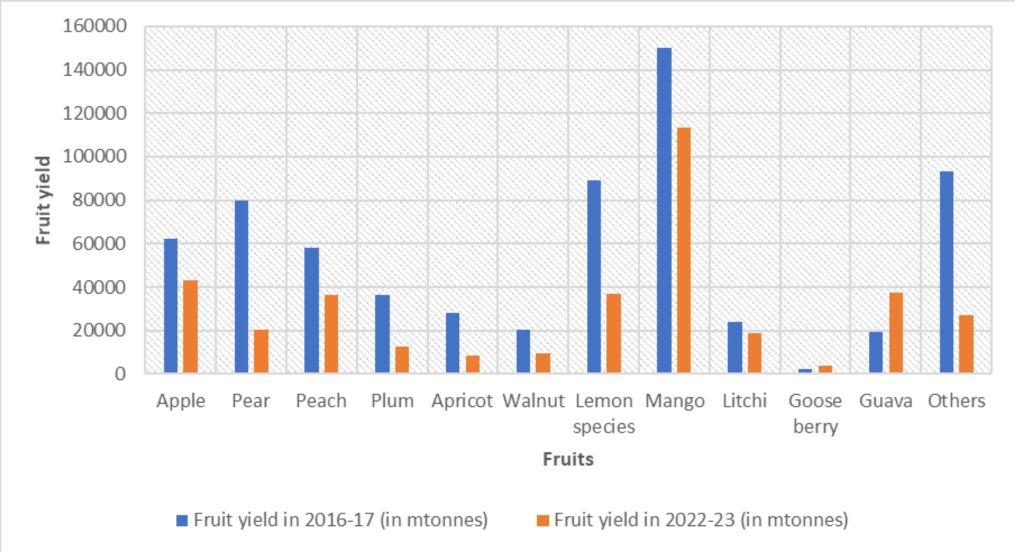


Figure 2: Changes in Yield of Different Fruit Cultivation between 2016 and 2023
Source: Department of Horticulture, Government of Uttarakhand

1.3. Rationale

1. This research aims to capture how shifting rainfall and temperature patterns are impacting the supply chain of tropical fruit crops in Uttarakhand at all stages including cultivation, transportation, storage and sale.
2. It further documents new scientific innovations and adaptation practices undertaken by farmers in an attempt to build resilience in the horticulture sector of the state.

2. Methodology

2.1. Study Location

The state of Uttarakhand was carved out of Uttar Pradesh on 9th November, 2000, to become the 27th state of the Republic of India. It has a total geographical area of 53,483 km2 and lies between the latitudes 28°43'N to 31°27'N and longitudes 77°34'E to 81°02'E (Uttarakhand BioDiversity Board). Situated on the south slope of the Himalayan range, the state has an altitude varying between 210-7817 metre above mean sea level with 93% of the area being mountainous while 64.81% is covered in forest (Barua et al; 2020). As per Census 2011, the total population of the state is 10.09 million with the density of 189 persons per sq. km (Barua et al; 2020).

Uttarakhand is divided into five distinct litho-tectonic and physiographic regions, including the Outer Himalayas, Sub-Himalayan Siwalik, Lesser Himalayas, Great Himalayas, and Trans-Himalaya. While the highest elevations are covered by ice and snow, the upper Gangetic Plains, moist deciduous forests and the drier Tarai savanna and grassland cover the lowlands along the border of Uttar Pradesh (UKIHDP, 2022). The state is further divided into two geographical and cultural regions: Garhwal in the northwest and Kumaon in the southeast. Its climate varies from hot and moist subtropical in the plains to cold alpine in the upper Himalayas and temperate in the middle regions (Barua et al; 2020).

An in-depth field study was conducted on fruit cultivation in the Kumaon sector of Uttarakhand. The landscape of the Kumaon Himalaya is comparatively gentle and consequently, the arable land is fertile, which has a significant impact on the production and the productivity of fruits (Sati, 2022). According to the State Horticulture Mission data, Nainital (8.96) has the highest productivity of fruits in the state followed by Udham Singh Nagar (7.91).

Bazpur, Kashipur, Sitargang and Rudrapur blocks in Udham Singh Nagar and Ram-Nagar and Haldwani blocks in Nainital were selected to assess the impact of climate change on the cultivation of tropical fruit varieties namely mango, litchi and guava cultivated in the foothills of the Himalayas. The study explored climate impacts on fruit cultivation and sale as observed by the fruit farmers, wholesalers and retailers in the selected blocks.

Table 2: Geography of the Chosen Districts

Blocks	District	Elevation	Terrain	Climate	Soil	Fruits Cultivated
Rudrapur, Bazpur, Kashipur, Sitargang	Udham Singh Nagar	214 metres	Tarai	Subtropical, sub humid	Alluvial	Mango, Litchi, Guava
Ram Nagar, Haldwani	Nainital	305 metres (Ram Nagar)	Bhabar	Subtropical highland climate	Alluvial mixed with boulders and shingles	Mango Litchi Guava

Source: District Profiles, Government of Uttarakhand

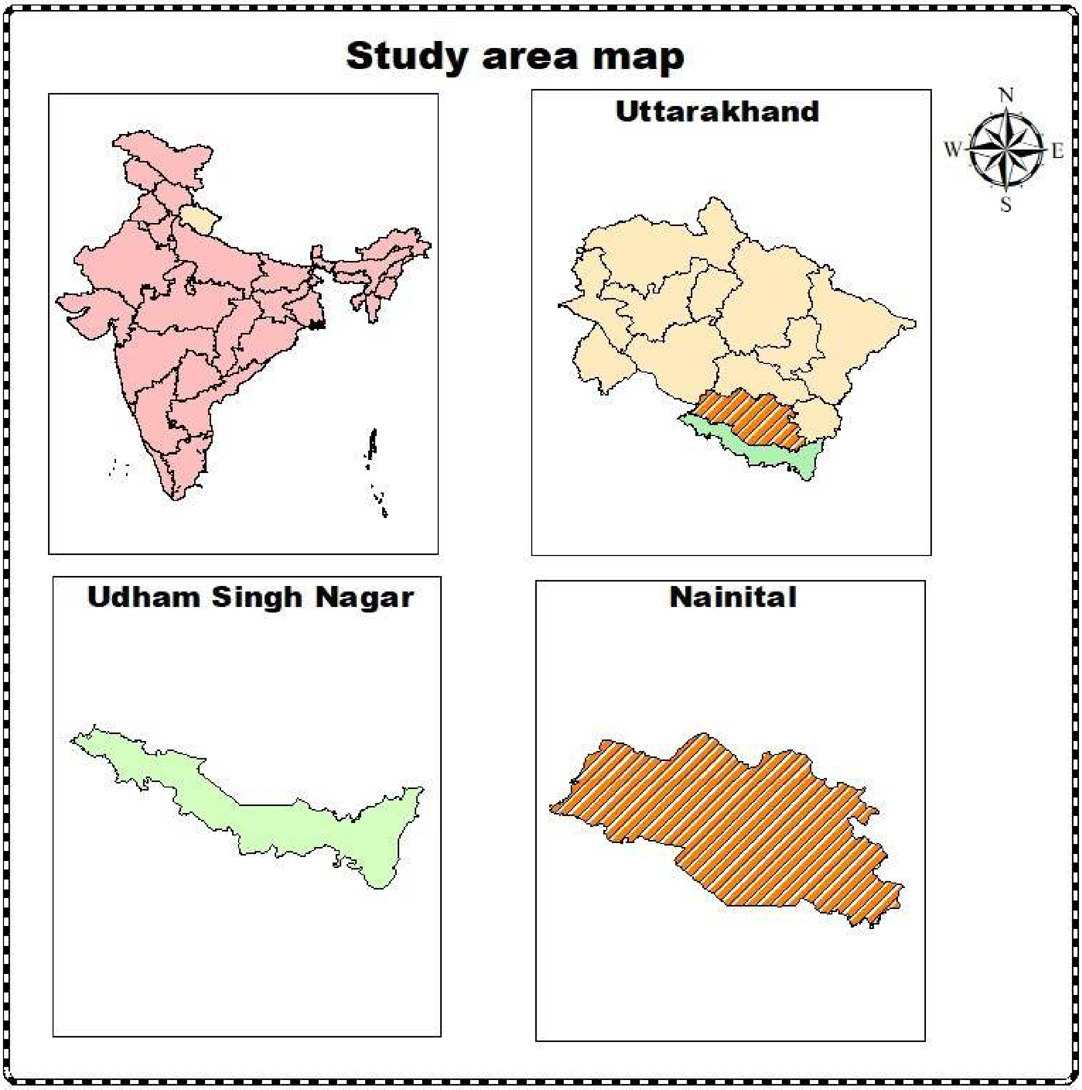


Figure 3: Study Area Map

Wholesalers and retailers of fruits from the Haldwani market were a part of this research. Haldwani hosts the major APMC market in the Kumaon region serving 363 villages in the vicinity. Around 200,000 producers visit this market annually from both the plain areas and the hill districts (Kharkwal et al; 2020). Having separate segments for tropical and temperate fruits, this market receives produce from the fruit belts of Mukeshwar, Almora and Pithoragarh in higher altitudes while also serving the plains and foothills. Due to limited market access in the hills, Haldwani has emerged as the single most important point of contact for buyers and sellers from the mountains.

2.2. Study Population

In depth qualitative interviews were conducted with fruit cultivators to assess the impact of heat, erratic rainfall and extreme events on their cultivation and identify locally led adaptation practices.Traders (commission agents cum wholesales) from Haldwani (Nainital) and Baghwada (Rudrapur) Mandis and retailers from local markets and street side stalls in Rudrapur were interviewed to understand how heat and extreme rainfall disrupts the sale of fruit crops in the state. Expert consultation with horticulturists from the G.B Pant University. 50 people were interviewed between 11-20 July, 2024 for this research.

Table 3: Details of Respondents

Respondents	Number in Each Category
Fruit Farmers	20
Wholesalers	10
Retailers	10
Horticulture Experts	10
Total	50

3. Findings

3.1. Climatological Trends in Uttarakhand

Uttarakhand is climatologically sensitive, ecologically fragile and highly vulnerable to natural disasters. The state has recorded approximately 1.5-degree Celsius warming between 1970 and 2022 with higher elevations experiencing amplified rates of warming. Average temperature in Uttarakhand increased at an annual rate of 0.02 degrees Celsius over the same period. Warming has induced changes in rainfall patterns and intensified climate extremes.

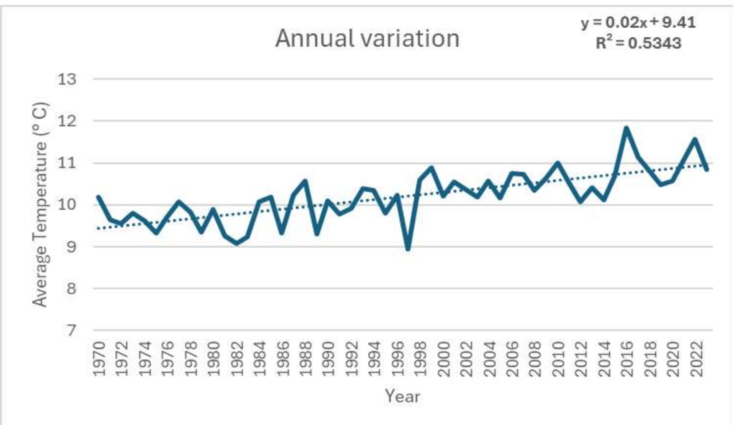


Figure 4: Temperature Trend in Uttarakhand between 1970 and 2022

Source: Climate Central

Rainfall Variability

Rainfall patterns have shown considerable interannual variability over the past century, with a reduction in the number of rainy days since the 1990s, particularly in the hilly regions of the state. While the total rainfall has not decreased significantly, the frequency of extreme rainfall events has increased (Upadhyay et al; 2020). A study conducted by the Council on Energy, Environment and Water reveals that several tehsils in the state have seen a decline in rainfall during the initial monsoon months of June and July in the past 40 years. The analysis also highlights a decline in October-November-December rainfall in the states of Uttarakhand with approximately 86 percent of tehsils in Uttarakhand experiencing a reduction in the northeast monsoon (Prabhu & Chitale, 2024).

Shrinking Snow Cover Area: Research reveals that relatively warmer winter temperatures in the higher altitudes have accelerated snow melt triggering a rapid decline in snow cover areas. In the past 20 years, winter temperatures at high elevations of the state have increased at the rate of 0.12◦C/decade. Precipitation has fallen by 11.2 mm per decade resulting in a rapid shrinking of Snow Cover Area at the rate of -58.3 km2 /decade. In Uttarkashi, Chamoli, Pithoragarh, Rudra Prayag districts Snow Cover Areas have shrunk by nearly 90-100 km2in 2020 as compared to 2000 (Banerjee et al; 2021).

Extreme Weather Events: Uttarakhand has been in the eye of recurring disasters ranging from extreme rainfall events, flooding, hailstorms and landslides resulting in significant damages to agricultural fields and standing crops. According to India's Atlas on Weather Disasters, in 2022 the state witnessed 57 days of extreme weather conditions (CSE & DTE, 2022). The number rose to 94 in 2023 when 44,882 hectares of farm lands were lost to extreme weather events (CSE & DTE, 2023).

Over 85 percent of districts in Uttarakhand, which are home to over 9 million people, are hotspots of extreme floods and its associated events (Mohanty &Wadhwan, 2021). The frequency and intensity of extreme flood events in Uttarakhand have increased fourfold since 1970. Similarly, associated flood events such as landslides, cloud bursts, glacial lake outbursts, etc. have also increased four-fold during this period, causing massive loss and damage. The state's Chamoli, Haridwar, Nainital, Pithoragarh, and Uttarkashi districts are the most vulnerable to extreme floods (Mohanty &Wadhwan, 2021).

Warming induced heat stress, erratic rainfall patterns and disease prevalence negatively affect yields necessitating a shift towards climate resilient practices to safeguard the horticulture sector from future risks.

3.2. Fruits Cultivation Profile in Udham Singh Nagar and Nainital

Nainital is the largest producer of litchi in Uttarakhand followed by Udham Singh Nagar which ranks the first in mango production among the states of Uttarakhand, with Nainital occupying the second position. Udham Singh Nagar is also the leading producer of guava in the state.

Table 4: Fruit Cultivation Profile in Nainital

	Mango			Litchi			Guava	
	Area under Cultivation	Yield		Area under Cultivation	Yield		Area under Cultivation	Yield
2016-17	2634.08	32754.79		1805	9262.67		474	2423.62
2022-23	2318.35	25462.92		1657.63	8100.06		284.05	2333.57

Source: Department of Horticulture, Government of Uttarakhand ***Area in Hectares, Yield in Mtons**

Nainital saw a 22% and 11% dip in the yield and area under mango cultivation. The yield of litchi in Nainital dropped by 12 percent for an 8 percent decline in area. The reduction in guava yield was a miniscule 3 percent despite nearly 40 percent shrinkage in area under cultivation. The study attempts to explain these trends in fruit cultivation through in-depth interviews with farmers and horticulture specialists. It further documents how farmers are maintaining fruit productivity in the face of climatic stress.

Table 5: Fruit Cultivation Profile in Udham Singh Nagar

	Mango		Litchi		Guava	
	Area under Cultivation	Yield	Area under Cultivation	Yield	Area under Cultivation	Yield
2016-17	4143	35216	1481	2229	1200	9627
2022-23	3690.5	28102.4	1497	5904.55	1705.72	22515.78

Source: Department of Horticulture, Government of Uttarakhand ***Area in Hectares, Yield in Mtons**

The yield of guava has increased by 133 percent in US Nagar between 2016-17 and 2022-23 despite 42 percent shrinkage in the area under its cultivation in the district. Litchi yield has increased by 165 percent in the same period for only 1 percent expansion in area under cultivation. Mango exhibits a declining trend with 20 percent reduction in yield corresponding to a 10 percent fall in area under cultivation.

3.3. Climate Change Impacts on Tropical Fruits Cultivation in Uttarakhand: Perspectives from the Ground

Tropical fruits namely mango, guava and litchi are mainly cultivated in the river valleys and plain regions in the sub-tropical climatic zone, which lies mainly >500 m in the state of Uttarakhand. The Tarai and Bhabar regions of Nainital, Udham Singh Nagar, the river valleys of Almora and Haridwar districts are notable for their production (Sati, 2022). The loss in yield and area of production have not been drastic for tropical fruits in Uttarakhand in the past seven years. They are however not immune to climate impacts.

3.3.1. Litchi (Scientific Name: Litchi chinensis)

Highlights:

- India is the second largest producer of litchis in the World after China (National Horticulture Board).
- Litchis thrive best under moist subtropical climatic conditions, have limited shelf life and are available in the market for a very short duration between May to June.
- They are adapted to the tropics and warm subtropics between 13° to 32°N and 6° to 29°S.
- They grow best in regions where winters are short, dry and cool (daily maximums below 20° to 22°C) but frost free, and summers that are long and hot (daily maximums above 25°C) with high rainfall (1200 mm) and high humidity (HMNEH, n.d).
- Litchis can tolerate relatively high temperatures during growth and flowering. The normal day temperature limit during the most sensitive growing phase is 40°C. It grows satisfactorily well under temperatures ranging from 20°C to 35°C; the optimum being 30 degrees Celsius (HMNEH, n.d).
- Ram nagar in Nainital district of Uttarakhand is a recipient of the Geographical Identification (GI) tag for its *Rose-Scented* litchis (Singh, 2023). Farmers apprehend that continuing trends of extreme summer temperatures under conditions of climate change may jeopardise the future prospects of litchi in the belt.

Climate Change Impacts on Litchi Production in Uttarakhand

- **Disappearing Spring Affects Flowering in Litchis:**

Flower initiation litchis start in January and continue up to the end of February. It is profoundly affected by variations in temperature and humidity. Farmers noted that since the past two or three years, the duration of spring is shrinking with temperatures transitioning quickly from winter to summer like conditions. In 2024, North India had weaker warming and cooling in December and January (Climate Central, 2024). The patterns changed dramatically after January with India experiencing its hottest February since 1901 (Copernicus Climate Change Service). In Northern India the contrast between January trends (cooling and slight warming) and February (strong warming) means that these regions now have the potential to abruptly transition from cool winter-like temperatures to much warmer conditions that traditionally occurred in March. Uttarakhand noted more than 2 degrees Celsius difference between January and February in 2024 as compared to the 1970s (Climate Central, 2024). Abrupt rise in temperatures in February interfered with the flowering of litchis.

- **Sun-Burn and Fruit Crack in Litchis from Extreme Heat:**

Extreme heat (temperatures soaring above 40.5 degrees Celsius) is detrimental to the growth of litchis. The Summer of 2024 was a punishing one, with severe heat waves gripping almost all districts of Uttarakhand with the mercury in Ram nagar exceeding the 40-°C mark for several days in the months of May and June. This was accompanied by lack of pre-monsoon showers leading to hot, dry summer months.

The scorching heat induced sun burns of unprecedented magnitude in litchis turning their outer skin dark and unsuitable for commercial sale.

> "All fruits experience natural inter-annual fluctuations in yield. In some years the produce is high while it is low in others. But the yield of litchi has been progressively deteriorating due to sweltering heat waves in the past three years culminating in a disproportionate loss of 75 percent yield this year due to sun-burn and stress induced fruit drop. Previously there used to be poor production in one out of 5 cycles. Now three out of five cycles are ruined due to heat", lamented Mr Deep Belwal, who cultivates litchis and mangoes in Ram Nagar.

Rising atmospheric temperature and low soil moisture and relative humidity can cause the skin to crack in litchis. Temperature higher than 38°C in combination with relative humidity lower than 60% increases the propensity for cracking of litchis. Inadequate moisture during the early fruit growth coupled with high temperature affects cell division, making the skin hard and inelastic. When irrigation is applied to the plants, the aril (the white, translucent flesh of the fruit) continues to grow, exerting internal pressure on the skin, causing it to rupture (Marboh et al; 2017).

- **Heat Induced Fruit Dropping**

Sometimes even after profuse flowering and fruit set, poor yield has been observed in litchis because of heavy fruit drop before maturity. External factors like high temperature, low humidity and strong westerly winds working in tandem with nutrition and hormonal imbalance in plants can induce fruit drop (HMNEH, n.d). Farmers in Ram Nagar attributed record breaking summer heat and erratic patterns of pre monsoon showers to excessive fruit drop and yield losses in litchis. They concur that such trends coincide with increasing frequency and intensity of heat extremes in the region since 2022.

- **Heat Impacts the Size, Colour and Texture of Fruits**

Farmers observed that the high temperatures adversely impacted litchi fruit development in US Nagar this year. The fruits remained undersized. Premature ripening caused the skin to turn red earlier than expected. Elevated temperatures affected the pulp, rendering it less juicy and watery.

Figure 5: Fruit Crack and Sun Burn in Litchis

Adaptation to Dry Heat in Litchis

- **Rain gun technology** has been deployed to mitigate the effects of extreme heat on litchi cultivation, particularly to prevent sunburn by maintaining moisture levels.
- **Bagging of fruit** bunches or covering the trees in plastic sheets can prevent direct sun exposure and prevent burn.
- **Moisturising the fruit skin** is crucial, as sufficient moisture helps protect it from sunburn and cracking.
- **Flood irrigation** in the orchards also proved beneficial in coping with dry summers

"Moisture is important for litchis. My orchards are surrounded by fisheries. During summer humid air from the fish ponds moistened the skin of the litchis, preventing them from drying out," Mr Shwetanshu Chaturvedi shared how he maintained good yield in his orchard in Ram Nagar, despite extreme heat this year.

Figure 6: Rain Gun Irrigation
Source: Google Photos

Figure 7: Covering Trees to protect from Heat
Source: The Photo was collected from field

Figure 8: Bagging in Litchis
Source: Google Photos

3.3.2. Mango (Scientific Name: Mangifera indica)

Highlights:

- Mango varieties like Bombay Green, Dasheri, Langda, Chausa and Fazli have traditionally been cultivated in the plains and lower hills of Uttarakhand which accounted for over 3.76 billion rupees in the fiscal year 2021 (Keelary, 2024).
- Mango is a heat-tolerant crop, but it grows the best in humid, semiarid subtropics and monsoonal tropics.
- The most suitable temperature for the growth of mango is 22 to 27 degrees Celsius.
- Mango plants thrive within a rainfall range of 1,000 to 2,500 mm annually, accompanied by a dry spell lasting 4 to 6 months each year. However the crop's potential production capacity is diminished under conditions of excessive heat, drought and increased evaporative demand (Khalifa & Abobatta, 2023).

Climate Change Impacts on Mango Production in Uttarakhand

- **Warmer Winters Leads to Off-Season Flowering in Mangoes:**

In Northern India flowering in mangoes happens between February and March. The flowering season in mangoes is mainly influenced by climatic conditions, especially the temperature level. The ideal temperature range for flowering of Langra mango for example, is between 15.5°C to 18.5°C (Geetha et al; 2016). It can be negatively impacted by the erratic distribution of cold nights and relatively warm winters (Khalifa &Abobatta, 2023).

"This year the emergence of panicles in mango trees started in the second fortnight of December when the maximum temperature remained between 25-28 degrees Celsius. Consequently, a fall in temperature in January damaged the panicles," mentioned Professor A.K Singh from the Department of Horticulture, G.B. Pant University of Agriculture and Technology.
He further added that " Once the fruits set in, temperatures rose dramatically in March, inducing fruit drop. This happened for the first time this year. "

- **Fruit Crack due to Extreme Weather Conditions:**

Premature mango ripening, as well as fruit cracking are caused by temperature increases around the period of fruit maturity (Haldar et al; 2024).

Typically, fruit rupture in mangoes manifests as splits in the skin and flesh, exposing the stone or seed, rendering the affected fruits unmarketable. Severe fruit cracking has been associated with dry periods followed by heavy rainfall and high humidity. Extremes in temperature, humidity, and rainfall contribute to the rupture. In affected fruits, the stone may exert pressure on the pulp and skin when the fruit absorbs water and expands, leading to cracking in fruits with thinner pulp (Saran et al; 2015). In the sub-tropical regions of Uttarakhand, Dasheri was identified as the most susceptible to fruit cracking (Saran et al; 2015).

Mango requires good rainfall during its growing season (June to October). Rains at fruit maturity are beneficial for the improvement of fruit size and quality (Naidu et al; 2018). While the North Indian cultivars can grow in a variety of rainfall conditions, the distribution of rainfall is more important than the amount (NHB). Long duration of intense heat waves and lack of pre-monsoon showers followed by spells of extreme rainfall in the first week of July, reportedly affected the quality of yield this year in Ram Nagar and Udham Singh Nagar.

"The year 2024 witnessed a rapid rise in temperatures from March inducing flower drop. This was followed by lack of pre monsoon showers in April and May and high heat in June which prevented mangoes from attaining their optimal sizes. Extreme rainfall in the first week of July caused the mature fruits to rupture. Nearly 50 percent of the mangoes in my orchard have cracked. The mangoes are still under harvest but I am anticipating a 30-40 percent yield loss as compared to previous years," mentioned Mr Deep Belwal, who owns mango orchards in Ram Nagar.

" Drop in yield and poor quality produce translate to monetary losses. Only a good quality produce can fetch a decent price. Last year langda mangoes from my orchard sold at 35 rupees/Kg. This year it would not go beyond 24 rupees/Kg," he further added.

Fruit cracking in mangoes or litchis are not new phenomena. But the magnitude and frequency of their occurrences have increased due to extreme weather conditions prevailing throughout the summer-monsoon period.

Mango cultivators and sellers reported that 2024 witnessed a bumper yield of mangoes but the size, quality and sweetness remained unsatisfactory. Moreover, extreme temperatures and rainfall slowed down the process of harvesting with labourers succumbing to heat exhaustion.

Figure 9: Fruit Crack in Mango

Climate Change Adaptation through Diversification of Varieties and High Density Plantation:

High-density orcharding is a modern fruit cultivation method where trees are planted closer together than in traditional methods to increase overall yield, making it crucial for boosting productivity, especially on small or fragmented land. With the increasing pressure on land and reduction in average size of land holdings, shifting to high density planting makes trees more precocious, heavy yielders and ones that bear better quality fruits. It helps to cope with land degradation due to floods and erosion. Increase in overall yield aids in recovering from fruit loss caused by extreme weather conditions.

A 20-year-old traditional variety of mango tree could produce 50-60 fruits on an average. In high density cultivation the yield of individual plants is reduced. An individual tree yields 1 quintal fruits in low density orchards while yield per tree is 30-40 kgs in high density plantations. But the total yield is more in the latter due to greater number of trees - A.K. Singh, Professor, Department of Horticulture, G.B. Pant University.

Traditional varieties of mangoes like langda and dasheri bear fruits in alternate years. Regular bearing hybrid varieties can boost farmer incomes by increasing yearly yield. They produce fruit within three years, whereas traditional varieties take 7-8 years (Nautiyal et al; 2021). High-density orchards with hybrids like Amrapali, Arunika, Ambika, and Mallika varieties, have opened new commercial opportunities for mango production in the plains and foothills of Uttarakhand. High density cultivation is also practised in other fruits like guava, apples, etc.

Figure 10: High density cultivation

Figure 11: Hybrid Varieties of Mangoes
Source: IARI

3.3.3. Guava (Psidium guajava L.)

Highlights:

- Guava is the fourth most widely grown fruit crop in India Guava predominantly cultivated in tropical and subtropical belts (Mitra & Pathak, 2007).
- It has recently gained popularity among farmers in Uttarakhand with nearly 95 percent increase in yield in the state in the past few years.
- L 49 (Sardar), Pant Prabhat, Allahabad Safeda, Lalit, Thai Golden 8 are some of the well known varieties of guava in Uttarakhand.
- The trees bear fruits twice a year: in monsoon and in winter.
- Guava is attuned to both tropical and subtropical climates.
- It grows best with an annual rainfall around 1000 mm restricted between June and September.
- A temperature range of 23–28°C (73 to 82°F) is ideal for the cultivation of guavas. However, the The trees can tolerate temperatures ranging from 15–30°C, but growth slows below 15°C (Fischer & Melgarejo 2021).

Climate Change Impacts on Guava Cultivation in Uttarakhand

- **Extreme Rainfall Events Deters Monsoon Yields**

Guava is highly sensitive to extreme rainfall and water logging in the field. It does not tolerate 'wet feet' and prefers well drained soil (NHB). Well distributed rainfall of moderate intensity between June and September favours its growth. Heavy and uneven rain can result in inferior quality, insipid, watery, insect-infested fruits (Mitra & Pathak, 2007).

Most growers in Uttarakhand regulate flowering in guavas to eliminate inferior quality monsoon crop in favour of better quality yields in winter. However, some farmers claimed that varieties like Golden 8 and Lalit produce decent fruits in the rainy season. But erratic rainfall patterns in the state over the past few years are making guava cultivation increasingly difficult.

> "The exponential rise in extreme rainfall events has affected fruiting in guavas. The taste, quality and appearance of the fruit have deteriorated. Three to fours days of moderate rainfall in a week is fine. But heavy spells of continuous rainfall are the problem as they do not allow the soil to dry.", shared Yatin Sighal who cultivates guava in Bazpur, Udham Singh Nagar. He further added that "Last year rainfall was extreme, 70 percent of the fruit were non sellable because of fungus attack due to high moisture content in the soil. In previous years only 5-7 percent of the fruits were lost to fungal attacks. But the quantum of loss increased drastically last year."
>
> "High temperatures and moisture in the summer monsoon period hastens the ripening process leading to smaller size of fruits lacking in taste and nutrition", mentioned Swetanshu Chaturvedi, a farmer from RamNagar in Nainital.

Farmers also noted that unusual heat, higher than usual temperatures and intense summer loo in 2024 induced flower drop in the winter variants of guava in May and June. The decline in water table and erratic supply of electricity hampered motor based irrigation which could protect the trees from the harsh weather conditions

Figure 12: Fungus Infected Guavas

- **Winter Yield Protects from Extreme Climate in Summer-Monsoons**

Guava trees thrive in tropical and subtropical climates and are well-suited to withstand the high temperatures and drought conditions common in northern India during the summer (NHB). In Uttarakhand, guava cultivation has witnessed a significant increase in yield over the past seven years, making it an ideal crop for warming conditions.

"*Amrud ek aisa phal hain jisme mausam ki maar kaam hoti hain* (Guava is a fruit which is less affected by weather aberrations)," stated Rajesh Dabral who grows guavas in his 35 acres land in Bazpur, Udham Singh Nagar.

The L49 variety is particularly popular, producing medium-sized fruits with an average reported yield of 1.5-2 quintals per tree. Farmers shared that guava cultivation is relatively low maintenance, requiring an annual investment of ₹15,000-20,000 per acre and generating an average income of ₹80,000-1 lakh per acre. Guava emerges as a climate resilient crop as it allows the farmers a certain flexibility in the production process enabling them to adapt to extreme weather conditions.

Crop Regulation in Guava to Adapt to Erratic Monsoons: In northern India, guava bears fruit twice a year—during the monsoon (July-August) and in winter (October-December). However, monsoon crops fall prey to extreme rainfall and moisture retention destroying yields. To avoid losses, farmers can regulate the flowering period and opt for a winter harvest when climatic conditions are more favourable.

Farmers reported that winter fruits, which ripen gradually in cooler temperatures, are of superior quality, with better taste, size, and nutritional content, compared to those ripened in the monsoon, which are exposed to high moisture and heat, leading to rapid ripening and reduced quality.

"Monsoon fruits weigh around 200 gms while the winter yield is bigger in size, sweeter in taste and weighs around 300 gms on an average," mentioned Mr Shwetanshu Chaturvedi, who cultivates guava as an intercrop in his mango orchards.

Crop regulation is practised to encourage the production of high-quality, commercially valuable fruits during the winter, which are preferred over the rainy season crop due to their superior quality and higher market value (Boora et al; 2016).

Flowering in guava begins in April-May, with fruit ripening in June-July. Farmers can either harvest during the monsoon or delay flowering for a winter harvest. In April and May, flowers meant for the monsoon crop are removed to allow the trees to re-bud and produce new flowers and fruits for winter. This practice of discarding the summer/monsoon crop results in better-quality fruits in winter (Boora et al; 2016). Natural flower drop occurs in April due to higher temperatures, and farmers induce additional fruit drop by withholding water, applying urea to the soil, using hormonal treatments, and removing flowering branches. This process delays the natural growth cycle of guava by two months, resulting in fruit that ripens in November-December instead of June-July. However, this year easterly winds interfered with the flowering process.

> "Guava is particularly affected by winds. Easterly winds bring moisture, while westerly winds are dry. Stress is necessary for fruiting, and withholding water encourages flowering. From December to June, guava orchards undergo pruning and management, during which irrigation is stopped to induce stress. This year easterly winds brought in moisture in April and May which the leaves absorbed. The plants were not entirely stressed. This disrupted the flowering process," shared Yatin Sighal

- **Intercropping with Guava Trees**

Guava is an excellent crop for intercropping, with some farmers maintaining separate guava orchards while others integrate guava as an intercrop in their mango or litchi fields.

> "The guava tree has a lifespan of 15-16 years and begins bearing fruit quickly, with a short gestation period that allows for harvesting from the third year after planting. Unlike litchi trees, which are slow-growing, guava trees produce fruit early, providing an interim income while the litchi trees mature. After 15-16 years, trees perish and can be replaced with other crops. Although guava cultivation is profitable, its limited shelf life makes it most suitable for local markets," shared Mr Deep Belwal who uses guava as an intercrop in his litchi orchard in Ram Nagar.

Crop regulation, high density cultivation, using guava as intercrops have exponentially increased the yield of guavas in Udham Singh Nagar by 133 percent in the past 7 years despite 42 percent decline in area under cultivation.

3.4. Indirect Impacts of Climate Change on Fruits

3.4.1. Climate Change Increases Pest Infestations

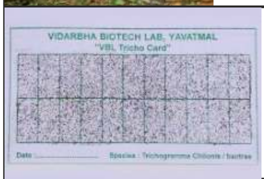
Temperature and precipitation are key drivers of pest and disease abundance in plants, with climate change expected to worsen their impact on fruits (Leng et al; 2023). Leafhoppers, which feed on mango leaves and transmit viruses during the post-bloom period, increase their feeding activity as temperatures rise (Leng et al; 2023). Fruit flies, a major threat to mango and guava, lay eggs under fruit skins during the monsoon, with maggots causing fruit damage and drop (Mitra & Pathak, 2007). Their populations peak in humid, rainy conditions, correlating positively with temperature, humidity, wind, and rainfall, but negatively with sunshine (Megha et al; 2023, Patel et al; 2019). High heat, especially temperatures above 36°C, reduces fruit fly infestations, with extreme heat waves protecting orchards this year (Rashmi et al; 2020).

High humidity, temperature from 28-32°C , poorly drained soils are favourable for initiation of fungal diseases in guavas[2]. One of the major fungal diseases is anthracnose in which the fungi affect all phenological stages of fruit, resulting in high yield loss. High relative humidity and temperature promote the incidence of anthracnose disease. Other disease outbreaks such as powdery mildew in mangoes is also strongly related to the relative humidity duration (Leng et al; 2023).

Integrated Pest Management for Combatting Pest Infestations

Agriculture extension centres like Krishi Vigyan Kendras (KVKs) which are entrusted with field demonstration and dissemination of cultivation technologies to farmers are promoting integrated pest management techniques in Udham Singh Nagar and RamNagar. The aim is to generate cost-effective, environmentally friendly pest control methods to reduce reliance on chemical pesticides. Integrated Pest Management (IPM) is an ecosystem-based strategy aimed at long-term pest prevention through a combination of techniques such as biological control, habitat manipulation, cultural practice modifications, and using resistant plant varieties[3]. The common strategies popularised by KVKs and used by farmers in the study area are listed below:

Table 6: Integrated Pest Management in Uttarakhand

Integrated Pest Management	Description
Mechanical Control	
 **Sticky Traps**	They use the colour yellow to attract insects, which then get stuck to its glue and die
 **Pheromone Traps**	A slow-release dispenser emits a pheromone that attracts and traps male insects preventing them from fertilising the females
 **Light Traps**	Insects are drawn to the light and fly into the collection chamber containing oil in which they get stuck
 **Tricho Cards**	These cards contain thousands of parasitized eggs that are used to fight pests by laying their own eggs inside the pest eggs
 **Solar Fencing**	Used to prevent attacks from monkeys, bats etc
Field Management techniques	Deep ploughing and heavy irrigation of orchards in October immediately after harvest to expose eggs and pupae of mealy bug and fruit fly
Biological Control	Beauveria bassiana, Metarhizium,Bacillusthuringiens, serve as biocontrol agents
 **Cultural Practices**	• Early harvesting of mature fruits in mangoes to avoid fruit fly infestation • Bagging of fruits in mangoes and litchis to reduce pest exposure

Source: Prepared by Climate Trends upon consultation with inputs from KVK scientists

3.4.2. Climate Change Disrupt Pollinator Activities

Effective crop pollination is heavily dependent on biological timing, of both the crop and its pollinators. Climate change may have profound impacts on the timings. The bees' need for nectar must coincide with its availability in the flowers. Mismatches may affect plant by reducing insect visitation and pollen deposition, while pollinators experience reduced food availability (Reddy et al; 2012)

Crops such as mangoes, litchi, etc., have periods of mass blooming over relatively short periods, requiring a tremendous peak in pollinators. Warming winters and disappearing spring seasons are shifting blooming months and influencing nectar availability in plants which can disrupt pollinator activities.

3.4.3. Fruit Cultivation Shifting to Higher Altitudes due to Warming

Farmers in Ram Nagar are observing a gradual increase in temperature in the belt due to rampant deforestation and shrinking forest covers. Once known for its best quality litchis, the rapid warming in the region is rendering it unsuitable for the cultivation of subtropical fruits. Optimum conditions for the cultivation of litchis are now available at higher altitudes.

> “Fruits which were available at 1500-1600 metres are now available at 2200 metres. The best environment for litchis have now moved to higher altitudes. This time the litchi which sold the best in Halwani was Jeolikote. Previously no one used to grow litchi in that belt. Now they are producing the best litchis” mentioned Deep Belwal.

3.4.4. Increasing Costs of Adaptation

Farmers contended that the cost of production has risen significantly, as they must now cope with climate extremes and their consequences, such as increased pest infestations, yield loss, damage to the orchards etc. Loss of quality and yield of fruits coupled with rising costs of adaptation have been escalating their expenses.

Erosion has become widespread due to heavy rainfall with those residing in foothills often facing flood-like conditions.

> “Last year, severe erosion created a large crater in my field, which I had to repair,” shared Deep Belwal, a farmer from RamNagar in Nainital.

He further added that irrigation in the Bhabar region previously relied on natural water sources like canals and rivers which are drying up due to extreme heat and erratic rainfall necessitating greater investment in irrigation. The Tarai region which once had an abundant supply of underground water is now suffering from declining water tables. Farmers have had to install more tube wells and borewells to fetch water from greater depths, increasing their expenses. A farmer in Bazpur had to install 2,000 additional tubewells to meet the high water demand in April and May.

> “Costs are also rising due to pest attacks requiring heightened application of insecticides and pesticides, the prices of which have escalated, especially following the Ukraine war,” mentioned Yatin Sighal, a farmer from Bazpur block in Udham Singh Nagar.

Table 7: Climate Change Impacts and Adaptation in Fruit Production in Uttarakhand

Climate Change Indicators	Impacts of Fruits	Adaptation Mechanisms Practised by Farmers
Extreme Heat	1.Sunburn, Fruit drop in mango, litchis	Bagging of Fruits, Irrigation through Flooding and Machine Gun Technology
	2. Post Harvest Losses	Ethylene Treatment to Extend Shelf Life, early harvesting in mangoes,night time transportation in cooler weather, covering fruits like litchis in leaves with leaves to retain moisture
Extreme Rainfall, Flooding and Landslides	1. Standing water leads to Poor Yield and pest infestation in Guava, Dragon Fruit	Landscaping of orchards, raised plant beds to prevent water logging, crop regulation in guava to avoid monsoon harvest
	2. Land degradation	High Density Orchards to generate more yield in smaller areas
	3. Increasing Pest Infestation due to humidity	Integrated Pest Management including mechanical, cultural and biological control to reduce reliance on pesticides
Warm, dry winters, shrinking snow cover area	Lack of chilling reduces yield of temperate fruits	Shift to Low Chill Varieties of Apples, Plum, Peaches etc
Water Scarcity		Drip Irrigation to reduce water usage, shift to drought tolerant fruits like dragon fruit, Kiwi, jujube cultivation

4. Impact of Climate Change on Fruit Supply Chains

Fruit Supply chains are facing climate adversities in the form of reduced supply of produce, transportation bottlenecks, and storage difficulties. Temperature and rainfall significantly affect the postharvest quality and firmness of fresh produce (NABCON, 2022).

4.1.Deteriorating Quality, Depreciating Market Value:

Fruit retailers and wholesalers in Udham Singh Nagar and Haldwani have reported a decline in the quality of fruits in the region. This year mangoes are smaller in size, litchis are sunburnt, and monsoon yields of guavas are poor in taste. The market for temperate fruits such as pears, apples, and peaches has been the worst hit. The production of temperate fruits has been consistently low for the past few years. The quality of the produce is inferior, with smaller sizes and visible blemishes leading to a reduction in prices. For fruits like mangoes, timely rainfall is crucial during ripening to achieve optimal sweetness and size. A lack of rain results in stunted growth and reduced quality.

"Aam ka season shuru hone se pehle barish zaroor chahiye. Barish nehi hoti toh aam ke andar jaan nehi aati. Mitha pan nehi aata. Size chota rahe jata hain", (The absence of rains during the growing period adversely affects the size, taste, quality of mangoes) a wholesaler from Bhagwada Mandi in Udham Singh Nagar commented on the small size of mangoes due to the lack of pre monsoon showers in the state.

4.2. Extreme Weather Conditions Spoils Fruits Faster Post Harvest

Elevated temperatures expedite the deterioration of fruit during storage and transportation, leading to heightened decay rates and reduced market value. Higher temperatures increase respiration rates, leading to faster decay. Guava experiences the highest postharvest loss at 15.05%, followed by mango at 12.74%. (NABCON, 2022)

Retailers shared that in months of May and June 2024 fruits perished faster than usual due to prolonged periods of intense heat. Mangoes generally last for two days after they are purchased by the retailers from the wholesale market. But this year fruits did not last longer than a day when temperatures soared to dangerous levels. A fruit seller in Udham Singh Nagar reported losses exceeding 1 lakh rupees this year in the summer months.

She further added "This was not the situation before. Fruits used to perish earlier as well in summer but now the quantum of loss this year was higher due to the drastic rise in temperature".

Fruits are subjected to reverse auctioning. Their price decreases with time as their freshness reduces. This process has been hastened by rising temperatures. Heat induced reduction in shelf life therefore affects the price of fruits. A fruit vendor in Udham Singh Nagar mentioned that the langda mangoes she got from the wholesale market would sell at 40 rupees/ kg, on the day of purchase. But their value will depreciate to 25 rupees/kg a day after as their freshness diminishes. Retailers lack the means of storing fruits in temperature-controlled environments to protect from heat. They sprinkle water on the fruits to ensure freshness and keep them cool during heat. They source the items on a daily basis after estimating their market demand to avoid spoilage.

They buy less ripened mangoes so that they last longer. A retailer in Nainital shared that due to the lack of adequate storage facilities at his shop, he has to travel 1.5 hours to Haldwani Mandi and purchase fruits in small quantities. He cannot acquire the products in bulk and it increases his overall costs. Extreme rainfall also disrupts transportation, storage and sale, particularly affecting vendors selling in carts without access to shade.

4.4. Increasing Reliance on Imported Varieties due to Decline in Local Supply

The local supply and quality of fruits have deteriorated over the years, leading to an increased reliance on imported fruits. Fruits imported from other countries are stored in cold rooms to maintain their quality. Imported varieties in Bhagwada Mandi in Udham Singh Nagar included apples from South Africa, plums from New Zealand, apricots and cherries from Afghanistan, and grapes from China. They fetch good prices and yield higher profits. However, these fruits, grown in vastly different climatic conditions with cooler summer temperatures, do not last long in India's climate, which is experiencing rising temperatures. To preserve their quality, they are transported in air-conditioned containers and stored in cold rooms shooting up electricity costs and energy usage.

"*Ab videshi phal zyada aa rahi hain*" (Imported fruits are flooding the markets these days), remarked a wholesaler at Bhagwada Mandi.

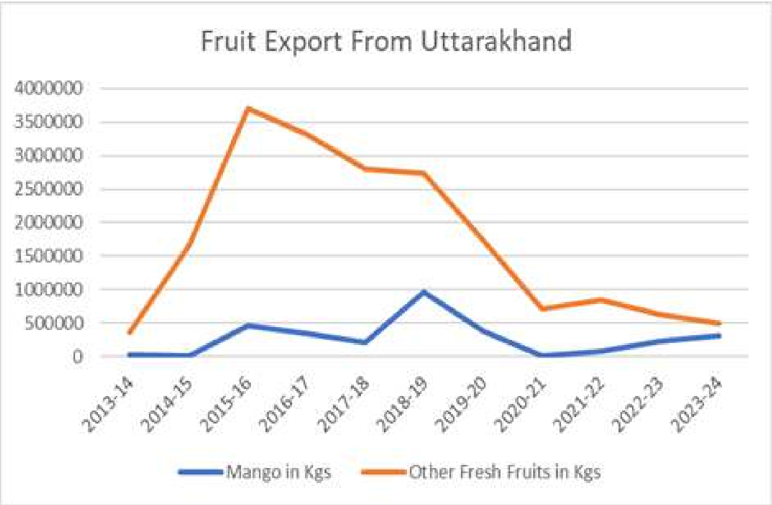


Figure 13: Decline in Export of Fruits from Uttarakhand Due to Poor Yield and Quality
Source: AgMark

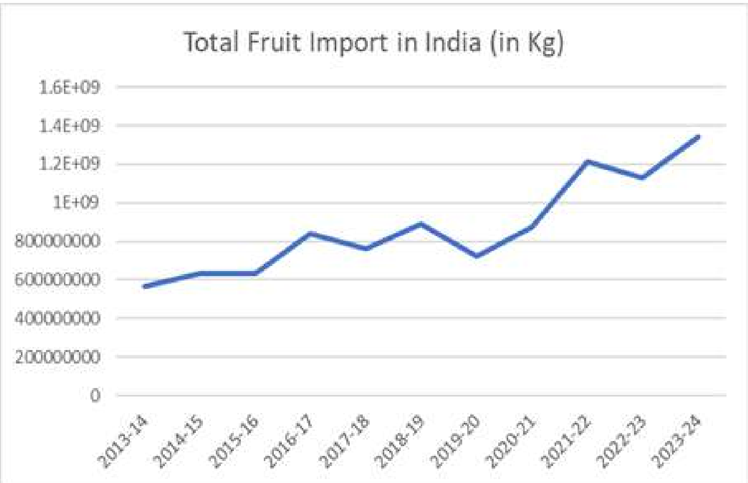


Figure 14: All India Increase in Fruit Import
Source: AgMark

4.5. Extreme Weather Events Affect Transportation of Fruits from the Hills

Transportation of fruits from the hills is often disrupted due to roadblocks caused by heavy rains and landslides, resulting in their erratic supply, affecting the incomes of sellers.

> Mr Deep Belwal from Ram Nagar said that "We load and transport at night when it's cooler. Delhi takes 6 hours. for the first time night time temperatures were higher. Nights did not cool down. High night time temperature during transportation can potentially reduce the shelf life of delicate fruits like litchis".

4.6. Extreme Heat Reduces Sale, Decreases Demand

Prolonged periods of extreme temperature in Udham Singh Nagar in June 2024 reduced the foot fall in local markets. Market demand for fruits like mangoes has been low, as people are consuming less to protect themselves from the heat. There was abundant mango harvest, and ample supply in May and June but low demand depressed the prices.

5. Innovations in Fruit Sciences in Response to a Changing Climate

While warmer temperatures hinder the growth of winter fruits, farmers are shifting to tropical alternatives. They are choosing low chilling cultivars of apples and peaches or replacing hard nut fruits like plum, peach, and apricots with tropical alternatives like kiwi. Dragon fruit is emerging as a viable crop in the plains of Uttarakhand due to its drought and heat tolerance.

5.1. Dragon Fruit: A Heat Tolerant Tropical Crop

Dragon fruit, native to Central and South America, is a resilient crop that thrives in various agro-climatic conditions, tolerating both high temperatures and water scarcity. It requires minimal water and nutrients, produces multiple annual harvests, and can yield for up to 20 years. Preferring tropical climates with temperatures between 20-29°C, it can also withstand extremes from 0°C to 40°C briefly (Wakchaure et al; 2021). With a high benefit-to-cost ratio, dragon fruit has gained popularity in tropical Asia over the past two decades, leading to global commercial cultivation.

Case Study: ***Climate Resilient Practices in Dragon Fruit Cultivation in Bazpur, Udham Singh Nagar***

Figure 15: Dragon Fruit Cultivation in Bazpur

Yatin Sighal owns a 16-acre dragon fruit orchard in Bazpur. In a bid to save the environment, Yatin practises organic farming in his orchard relying on manure to boost yield and biocontrol agents for pest management. Drip irrigation is a good alternative to cope with water scarcity which requires only a fraction of the water necessary for flood irrigation. He has installed micro sprinklers in his orchard to maintain the local microclimate in summers as dragon fruit requires an optimum level of moisture but cannot tolerate excessive standing water. Landscaping in the orchards have been done in a manner to ensure raised plant beds which prevents waterlogging.

Fruiting in the plants begins with the onset of the South West Monsoons in late June and continues until the first week of December. The fruit is harvested in cycles of 25 days, with 6-7 harvests occurring between June and December. Dragon fruit tolerate temperatures ranging from 5 to 40 degrees Celsius. Although the plants experienced stress during extreme heat in the summer, they managed to survive.

The annual running cost for one acre of dragon fruit is ₹1.5 lakhs, with an initial investment of ₹5 lakhs per acre. The expected returns from one acre are ₹5-6 lakhs per year at current prices. As dragon fruit is still relatively uncommon, demand is expected to increase, potentially driving up prices. He is optimistic about the future prospects of the fruit which he sells locally as well as distributes in big cities such as Haldwani, Moradabad, Kashipur, and Dehradun. A decent shelf life of one week in summer and two weeks in winter favours transportation to distant places. Big retailing chains like Big Basket, Reliance Fresh acquire his fruit whose price sometimes climbs up to ₹300 per kilogram.

The crop's long fruiting span between June and December allows for multiple harvests, Even if farmers incur losses in one of the cycles, they can easily recover from it in the subsequent cycles in the same year. Dragon fruit is a viable and profitable crop in the changing climate, with high yields balancing the high maintenance costs.

Yatin has planted jujubes in his orchard. The plantation, covering 2 acres, is currently 2 years old and has not yet reached its full potential, which is typically attained after 5 years. He feels that a tropical fruit like jujube with its heat tolerance till 40 degree Celsius is an excellent fit for the rapidly warming landscape of Udham Singh Nagar.

5.2. Low Chill Varieties of Apples and Peaches

Many peach varieties traditionally require 1600-1800 hours of chilling at temperatures between 4-7 degrees Celsius for successful production. However, new varieties of peaches and plums have been developed that require only 200-300 hours of chilling, without a significant difference in quality (Singh et al; 2007). Low-chill peach varieties, such as Florida Sun, Sun Red, and Sun Gold, are successfully cultivated in plain areas of Pant Nagar expanding their geography.

Premium varieties of apples like Red Delicious, Royal Delicious, and Golden Delicious, which require over 1600 hours of chilling, are becoming unviable in a rapidly warming climate of Uttarakhand. As a result, farmers are transitioning to low-chill variants such as Red Spur, Jeromine, and Red Vilox at higher altitudes, and Anna, Tropical Beauty, and Early Fuji in the lower hills and valleys (Nautiyal et al; 2020).

"Low-chill apples are typically harvested in June, while high-chill varieties are harvested much later, allowing for better market rates," mentioned Professor D.C. Dimri, Department of Horticulture, G.B. Pant University of Agriculture and Technology.

Case Study: Apple Cultivation in the Plains of Uttarakhand

Figures 16 & 17: Apple Cultivation in Sitarganj

Rajvinder Singh, a progressive farmer cultivates low-chill apple cultivars of apples in Kalyanpur village in the Sitargang block of Udham Singh Nagar. His organic orchard currently comprises 200 apple trees of the *Golden Dorsett* and *NRMN 99* varieties. Within three years of planting After three years of planting, each tree yields approximately 40-50 kg of fruit. Singh contends that low chill apples are particularly well-suited to tropical climates, making them a sustainable choice in the face of warming.

Golden Dorsett requires 250-300 hours of chilling and thrives well in temperatures between 7-9 degrees Celsius in winters. It is among the earliest to bloom, often as early as mid-January, with harvesting taking place in June. These trees are highly resilient to extreme heat and can withstand temperatures between 45-48°C and grow very fast. While high-chill apple varieties typically take over two years to bear fruit, low-chill varieties begin fruiting within just 13 months of planting. The water requirement is minimum. Rajvinder Singh uses drip irrigation in his field which he claims saves nearly 80 percent water as compared to traditional forms of irrigation. However, the shelf life of low-chill varieties is significantly shorter than high-chill variants and the apples must be sold within 10-15 days of harvest.

Although the trees survived the temperature extremes this summer the size of fruits remained small due to excessive heat, leading to lower prices. Last year, Singh sold his apples for ₹150 per kg, but this year, the smaller fruits fetched only ₹80-100 per kg. Furthermore, extreme rainfall and waterlogging also pose significant threats to these apple trees, which have shallow roots. Excess water can cause root decay and increase the risk of weed growth and fungal diseases.

Despite these challenges, Singh feels that the adoption of low-chill apple varieties has positively impacted his farm's profitability. Encouraged by the success of his orchard, he expanded his acreage this year by planting an additional 50-60 trees. He believes that low-chill apples hold significant potential to boost farmers' incomes, allowing them to expand apple cultivation beyond hilly areas. The economic benefits and heat tolerance of low-chill varieties make them a viable option for sustainable farming in regions with rising temperatures.

5.3. Kiwi: A Cure to Water Stress in Hills

Kiwi cultivation is expanding in the hills to cope with the increasing water stress. As a temperate fruit, kiwi offers several advantages, including minimal water and nutritional requirements, and the ability to grow on barren and uncultivable lands. It is primarily cultivated in the mid-hill regions at altitudes of 1800-2000 metres (National Horticulture Board). The fruit is in high demand and commands high prices, particularly in October and November when other fruits are scarce. A yearly rainfall of approximately 150 cm is sufficient for its growth.

5.4. Alphonso, Kesar, Benganpalli Adjusting Well to the Warming Climate of Uttarakhand

Farmers have introduced mango varieties from warmer regions like Kesar from Gujarat, Benganpalli from Andhra Pradesh, and Alphonso from Maharashtra to Ram Nagar and Udham Singh Nagar, where these varieties are adapting to the local climatic conditions. However, their fruiting cycles have shifted, with Kesar and Benganpalli producing fruit in July in Uttarakhand, after their production has ended in other parts of the country. Mr. Swetanshu Chaturvedi cultivates export-quality Alphonso in Ram Nagar.

> “The plants have significantly changed their characters here. These alphonso mangoes are different from the Ratnagiri variant. Ratnagiri is not as cold in the winters as Ram nagar. In Ratnagiri the plants grow in winters as well but in Ram nagar they go into dormancy due to cold weather. But the fruits are equally delicious,” he mentioned.

5.5.Delayed Rainfall Favours Grape Production in the FootHills

The Horticulture Research Centre at G.B. Pant University of Agriculture and Technology is currently experimenting with various grape varieties from Pune, Nashik, Hyderabad, and the USA to assess their suitability for the local climate of Uttarakhand. In North India, grape cultivation is challenging because the ripening time coincides with the onset of the monsoon leading to berry splitting and rotting. However, due to a shift in rainfall patterns and delayed rains, grape cultivation has improved, with some early varieties ripening before the monsoon. It has been observed that when grape varieties are introduced from other regions, their characteristics change, such as seedless grapes developing seeds due to different climatic conditions.

Figure 18: Grapes in the Horticulture Research Centre, G.B. Pant University

Conclusion

The impacts of climate change on horticulture in Uttarakhand are profound, reshaping the state's fruit cultivation patterns. Warming temperatures, erratic rainfall, and extreme weather events are reducing yields and shifting cultivation zones. The most vulnerable are temperate fruit varieties like apples and peaches, which are seeing declining productivity. Farmers are increasingly adopting tropical crops, such as guava and dragon fruit, as part of their adaptation strategies, reflecting the region's move towards climate-resilient practices. Climate change may extend the growing season, potentially allowing for multiple harvests or the cultivation of new fruit varieties. However, these potential benefits are often offset by the increased risk of extreme weather events, such as heatwaves, droughts, and floods, which can cause sudden and severe crop losses (Schlenker and Roberts, 2009).

The challenges of changing climatic conditions extend beyond production, affecting supply chains, marketability, and storage, which in turn impact the profitability of local farmers.

The findings underscore the importance of continued research, investment in resilient farming techniques to sustain Uttarakhand's fruit cultivation in the face of climate adversity. While the introduction of climate-resilient crops shows promise, a holistic approach encompassing both technological and market-oriented solutions is essential for ensuring long-term sustainability in the region's horticultural sector.

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