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# Implications of Changing Climate on Productivity of Temperate Fruit Crops with Special Reference to Apple

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## Abstract

Winter chill is essential for most of the plants that fall dormant in the winter in order to avoid frost damage and do not resume growth until a certain amount of winter chill has accumulated for fulfilling their chilling requirement. Climate change is likely to affect chilling requirement of temperate fruit crops significantly and therefore, the opportunity to meet this requirement will be reduced as the climate becomes warmer. Increase in average global temperature would move the existing plant species and varieties to new latitudinal belts with favourable climates. It is, therefore, possible that crops that are used to be productive in one area may no longer be so or the other way round. The resultant of these climate changes are clearly apparent in the shifting of apple cultivation from lower elevations to higher altitudes in India.

Insufficient chilling greatly influences flower initiation and fruit colouration along with deterioration in fruit texture and taste. Further, the lack of proper chilling is also posing serious problems like scab disease, premature leaf fall and infestation of red spider mite in apple. High temperature and moisture stress is increasing sunburn and cracking in apple, apricots and cherries in the higher altitudes. Insufficient chilling reduces pollination, fruit set and ultimately the yield in walnuts, pistachio and peaches. Advanced flowering has been found in olive, apple and pear. Reduced flower size and pedicel lengths were observed in cherry due to less chilling.

The studies regarding impact of climate change on fruit crops is meagre primarily due to lack of data, appropriate modeling and government policies. Development of low chill cultivars with greater tolerance to stresses, use of GIS to match varieties with the projected suitable production locations, development of suitable dormancy and chilling models, altering orchard microclimate and use of rest breaking chemicals are the viable approaches that can be adopted to yield reliable results on regional scale.

## Introduction

Climate change is a change of climate over comparable period of time that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere. The global mean temperature of the earth's surface has increased by about 0.74°C [1] over last hundred years. The variation in surface temperature indicated that 1990's decade has been the warmest in the past millennium and 1998 was the warmest year [2]. The rise in temperature is attributed to alarming increase in the atmospheric concentration of greenhouse gases viz., $CO_2$, $CH_4$, $N_2O$ and chlorofluorocarbons mainly due to accelerated rate of industrialization [3]. The expected carbon dioxide concentration in 2100 is estimated to be 100% higher than the one observed at the pre-industrial era [1]. With global temperatures expected to rise by up to 6°C by the end of the 21st century compared to pre-industrial levels [1], it is unlikely that this agro climatic metric will remain stable [4]. Higher evapotranspiration indices could lower or deplete the water reservoir in soils causing water stress in plants during dry seasons. Consequently, water stress not only reduces crop productivity but also tends to accelerate fruit ripening [5]. The global warming caused loss of vigour, fruit bearing ability, reduction in size of fruits, less juice content, low colour, reduced shelf-life and increasing attack of pests resulting in the low production and poor quality apple crop [6]. Vulnerability, rarity and rapid extinction of many species of temperate fruits will be among the other consequences of climate change.

The availability of natural resource for agriculture is decreasing because of growing demand of the increasing population. In India, the study on seasonal and annual surface air temperature has shown a significant warming trend of 0.57°C per hundred years [7]. Temperate fruits are mainly produced in the middle latitudes ranging from 30° to 50° N and S. Their cultivation may extends to lower latitudes (15°-30° N and S) at higher altitudes and to higher latitudes where large water bodies and congenial climate is available. Cool temperatures in the winter are essential for fulfilling their chilling requirements to ensure homogeneous flowering and fruit set and generate economically sufficient yields. In order to escape the damage of sensitive tissues from winters, trees from temperate or cold climates have evolved the mechanism of dormancy. After certain duration of cold conditions (chilling), endo-dormancy is broken and the tree is ready to resume growth in the following spring [8]. The chilling requirements (hours) of some important temperate fruit trees are listed in Table 1. The failure to meet the cold requirement results in abnormal growth of the tree. The apple tree requires 1200-1500 hours of chilling below 7°C depending on the type of cultivar. Chilling hours <1000 lead to low yield of poor quality. For breaking dormancy, trees must not only fulfil their chilling but also heat requirement at proper time [9]. The delay in the blooming dates of many trees indicate that dormancy breaking processes are indeed changing, most likely in response to climate change [10].

It has been reported that the rise in average temperature, long spells of drought during summer, delay in start of winter, reduced snowfall have reduced large area supposed to be marginally suitable for apple cultivation. The chill units critical for apple production have exhibited a decreasing trend. Trend analysis indicated that snowfall is decreasing at the rate of 82.7 mm/annum in the entire region of Himanchal Pradesh [11], consequently, the apple cultivation area is moving further up in elevation because of the warmer climate. Overall decrease of about 2-3% in yield has been reported in Shimla, Kullu, Lahul and Spiti districts in mid 2000s and the maximum decline of about 4% was witnessed in marginal farms [12] Apple-growing areas in low altitudes like Solan have been reported to reduce by as much as 77% between 1981 and 2007 [6]. In view of increasing concern for climate change, this review paper focuses on potential impact of changing climate on temperate fruit production and strategies to reduce risk and take benefits of potential opportunities.

## Winter chilling and heat unit accumulation

Winter chilling refers to a physiological requirement for low temperature to enable normal spring growth, and failure to obtain sufficient winter chilling results in a marked decline in both yield and fruit quality. Chilling requirement is defined as the number of effective chilling hours needed to restore bud growth potential in spring [13]. The chilling requirement is typically measured in terms of numbers of hours, during which temperature remains at or below 7°C during the winter season. The chilling requirements of different temperate fruits are presented in Table 1.

| Fruit crops | Chilling hours |
|---|---|
| Apple | 1000- 1500 |
| Pear | 1200 |
| Peach | 200-1200 |
| Plum | 1000-1200 (European plum) |
| | 700-1000 (Japanese plum) |
| Cherry | 2000-2700 |
| Almonds | 800 |
| Apricot | 300-900 |
| Walnut | 200-800 |
| Pecanut | 400 |
| Pistachio nut | 700-1000 |

**Table 1:** Chilling requirements (hours) of temperate fruits.

## Calculation of chill units

The security of fruit production is very sensitive to weather and changing climate. However, it is rather very difficult to express the agriculture related effects of the climate change in numbers and figures as the soil-plant-atmosphere system is very complex. Different simulation models of winter chill accumulation have been developed which are purely empirical and based on either field observations [14] or controlled temperature experiments [15] rather than on a functional understanding of tree physiology. The most widely used models to calculate chill units are as follows-

### Chilling hours model

The Chilling Hours Model is the oldest method to quantify winter chill [16]. According to this model, temperatures between 0°C and 7.2°C are assumed to have a chilling effect, with each hour at temperatures between these thresholds contributing one chilling hour. Chilling hours are thus accumulated throughout the dormant season and then summed up [17].

### Utah model

The Utah Model developed in Utah, USA. It contains a weight function assigning different chilling efficiencies to different temperature ranges, including negative contributions by high temperatures. This model of chill units (CU) defines a CU as the permanence of the buds for a period of 1 hour in a temperature range considered optimum (2.5-12.5°C) to accumulate chill. The model presumes that chill accumulation occurs within a temperature range of 2.5 and 12.5°C, outside of which, the accumulation is nil or negative [13]. Although this model provides good results in cool temperate climates, it is not accurate in areas with high winter day temperature (over 20°C) as it yields a large quantity of negative chill [18].

### Dynamic model

The Dynamic Model was developed in Israel [15]. It is based on the hypothesis that chill accumulation occurs in the form of portions or quantum of chill that takes place in two step processes. An intermediate product is first formed in a process promoted by cold temperatures. Warm temperatures can destroy this intermediate product. Once a critical amount of the intermediate chilling product has accumulated, irreversibly transforms into a Chill Portion which can no longer be destroyed. A certain chill portion accumulation indicates fulfilment of chilling requirement [19]. The model has given better results in warm temperate and sub-tropical climate. The majority of studies have found the Dynamic Model to be relatively accurate in different climates as compared to other commonly used Chilling Hours approach.

## Impact of climate change

**Effect on dormancy and chilling requirement:** Dormancy is a mechanism that plants use to protect sensitive tissue from unfavourable climatic condition [9]. The rapid climatic changes might alter the adaptability of many temperate fruit crops in the near future, and severe productivity problems might arise. Commercially successful cultivation of many fruit and nut trees requires the fulfilment of a winter chilling requirement, which is specific for every tree cultivar. Lack of chilling as in mild winter conditions result in abnormal pattern of bud-break and development in temperate fruit trees [20].

Impacts of climate change have been investigated for many cereals and oil seed crops, but relatively less is known about the potential impacts on fruit trees [21]. Baldocchi and Wong [22] projected a 50% decrease in chill hours from 1950 to 2100, approaching the critical threshold for many fruit tree species in California. When chilling requirements are not completely fulfilled, trees display irregular and temporally spread out flowering, leading to anomalous growth and inhomogeneous crop development [23]. Eventually, warming may affect over-winter chill requirements of temperate tree fruits and require replacement by new cultivars or species [24]. This process ultimately results in varying crop sizes and maturity stages at the time of harvest, which can substantially reduce yield and fruit quality [16]. Melting of ice cap in the Himalayan regions will reduce chilling effect required for the flowering of many of the horticultural crops like apple, cherry etc. [25]. Luedeling et al., [26] concluded that the areas where safe winter chill exists for growing walnuts, pistachios, peaches, apricots, plums and cherries (>700 chilling hours) are likely to almost completely disappear by the end of the 21st century. For cultivars with chilling requirements above 1000 chilling hours such as apples, cherries and pears, very few locations with safe chilling levels were found to exist today, and modelling results project that virtually none will exist by mid-century.

According to Vedwan and Rhoades [27], climatic changes alter the pattern of blossoming, bearing and, therefore, fruit yield, and the quality of apple under Western Himalayan condition of India. Grab and Craparo [28] reported that climate change advances the date of full bloom in apple and pear under South African condition. If winter chilling requirements is not fulfilled for the main commercial apple cultivars like in other regions, this would result in poor spread or delayed bud-break in southern Uruguayan conditions [29] and lack of synchronized bud-break with a negative effect on pollination [30]. The greater rise in winter and spring (January to March) temperatures lead to earlier flowering, which coincides with the time of spring frost resulting in a remaining risk of frost damage to apple flowers [31]. Campoy et al., [32] found chilling requirement differences higher than 50% for clonal plant material of apricot grown successfully in different climatic conditions. This variation might be associated both with different temperature and other factors such as latitude. Westwood [33] reported the effect of winter chilling on cellular division, and supposed that the small size of fruits is due to lack of winter chilling which results in lower cellular division.

In temperate climate areas, frost can also represent the main cause of weather related damage to crops. Apple and other temperate fruit are vulnerable to spring (late) frosts. During the bloom stage, a single event with temperatures going a few degrees below zero is sufficient to damage flower buds or even kill them. While light frosts result in the deterioration of fruit quality, severe frosts threaten the harvest itself [34].

**Effect on phenology:** The change in the timing of different physiological activities i.e. phenology is one of the most pronounced effect of climate change [35]. The analysis of phenological events for plants during the past several decades have been examined for quantifying a possible biological response to recent climate change [36]. In temperate fruits, flower induction is deeply influenced by temperature, especially low temperature, however, strong interaction between genotype, photoperiod and temperature interactively control flowering. In a study conducted by Wolfe et al., [37], it was observed that there was an advance in spring phenology ranging from 2 to 8 days for the woody perennials in north-eastern USA during period 1965 to 2001 and a qualitatively consistent and similar phenology shifts with a warming trend have been reported for other mid and high-latitude regions. An earlier date of full bloom of up to 10 days was observed in apple 'Boskoop', 'Cox's Orange Pippin' and 'Golden Delicious' when comparing the last 20 years with the previous 30 years, which is less than the 14 days reported generally for Germany [31]. Advancing trends in bloom dates of many trees indicate that dormancy breaking processes are indeed changing most likely in response to climate change.

**Effect on pollination:** Climate change, an emerging global phenomenon, with a potential to affect every component of agricultural ecosystems, is reported to impact bees at various levels, including their pollinating efficiency [38]. The changing climate scenario has contributed in significant reduction in the population of the pollinating insects. If the temperature is either very low or very high there is no fertilization, thus affecting fruit set. For fruits that are cross pollinated such as walnuts and pistachios, insufficient chilling can reduce pollination leading to reduced crop yields [39]. The optimum temperature for pollination and fertilization in temperate fruits like apple, pear, plum, cherry etc is between 20-25°C. Low temperatures and rainy or foggy conditions had observed to have a negative effect during pollination in sour cherry in USA [40].

**Effect on pest and disease incidence:** Insect life cycle processes affected by climate and weather include life span duration, fecundity, diapauses, dispersal, mortality and genetic adaption. High temperature in spring results in faster reproduction rate, thus the increase in pest population is rapid [41]. Efficacy of crop protection chemicals is affected due to changes in temperature and precipitation. In addition to direct impact of climate change on apple productivity, it has also aggravated infestation of some diseases and pests resulting in more losses in yield [42]. Dry and hot summer reduces the infection of Rhynchosporium leaf blotch and Septoria leaf spot diseases, but summer precipitation, particularly heavy storms, would increase the incidences of these diseases [43].

**Post-harvest quality:** According to Moretti et al., [44], temperature variation can directly affect crop photosynthesis, and a rise in global temperature can be expected to have significant impact on the postharvest quality by altering important quality parameters such as synthesis of sugars, organic acids, antioxidant compounds, peel colour and firmness. Grapes had higher sugar content and lower levels of tartaric acid when grown under high temperatures [45].

## Manipulation of the chilling requirement of temperate fruit trees

Once the tree cultivars are selected and planted in the orchard, it is required that they remain in production for decades. The need to anticipate and adapt to climatic changes is very much urgent for growers of tree crops. Even the already established commercial varieties of fruits might perform poorly in an unpredictable manner due to aberration of climate. This has led to the development of cultural, mechanical and chemical practices to alleviate the problem associated with insufficient chilling.

**Low chill cultivars:** This is the most feasible solution to the problem of insufficient chilling, however, it is very difficult to breed low chill cultivars. Modern biotechnological aspects in mapping the genetic determinism of chilling are required to boost up the breeding process with a view to develop appropriate cultivars for all major fruits within a reasonable time span. Re-evaluation of the fruit varieties as per the indicated climate changes is imperative for planning a new orchard. Introduction and adaptation of low chilling cultivars of crops like apple, peach, pear and plum in certain areas of lower hills and North Indian plains where they could be grown commercially. The low chill cultivars of some temperate fruits are listed below in Table 2.

| Fruit crops | Low chill cultivars | Chilling requirement |
|---|---|---|
| Apple | Anna, Mayan, Tamma, Vered, Tropical Beauty, Parlin's Beauty, Schlomit, Michel, Neomi. | <800 hours |
| Peach and Nectarines | Flordasun, Flordared, Sunred Nectarine, Sun Gold, Saharanpur Prabhat, Shan-e-Punjab, Sharbati. | <500 hours |
| Pear | Gola, Pathernakh (Sand Pear), Leconte, Kieffer, Punjab Nectar. | 150 hours |
| Plum | Santa Rosa, Jamuni, Alubokhara, Alucha purple, Titron, Satluj purple, Kala Amritsari. | -- |
| Apricot | New Castle, Early Shipley, St.Ambroise, Kaisha, Chaubattia Alankar. | -- |

**Table 2:** Low chill cultivars of some temperate fruits.

**Evaporative cooling:** The other approach to induce bud burst is to increase chilling hours by evaporative cooling of the buds under endo-dormancy period [46]. Evaporative cooling helps in reducing the bud temperature under mild winter condition and thereby increasing the number of chilling hours required for proper bud burst. Sprinkling with water to provide evaporative cooling during rest period had been found to advance the blooming of 'Flordagold' peach and 'Sungold' nectarine by 7 days [47]. Overhead irrigation has successfully been applied in Israel for cooling buds during the hottest hours of the day [48]. Allan et al. [49] reported the synergistic effect of Dormex and evaporative cooling by intermittent overhead sprinklers during the peak hot hours of the day in improving the bud-break and yield. Uzun and Caglar [50] delayed the blooming in pistachio by means of evaporative cooling that involved the sprinkling of water to cool fruit buds in order to delay their development.

**Heat treatment:** Temperature is often considered the most important factor influencing phonological phases of fruit trees in temperate climates. Higher temperatures enhance biochemical reactions, which consequently prolong the growing season and influence phonological phases of individual plants [51]. Heat shock proteins (HSPs) have been found in various plants and in some cases they have been found to increase with the chilling [52]. Tamura et al., [53] found nine HSPs to be accumulated when the trees were exposed to short-term high temperature treatment (45°C for 4 hours) and were responsible for inducing bud break in the floral buds of Japanese Pear 'Nijisseiki'. Similarly, pear plants when treated with water at 45°C for three hours, bud burst was induced [54]. Chandler [55] showed that bud burst was induced in apple trees when they were exposed to 44-46°C for six hours of a single or on two consecutive days in July, October and November.

**Dormancy avoidance:** The methods which can prevent the plants from entering into dormancy condition helps in bud burst without requiring chilling temperature. Griesbach [56] observed that dormancy can be induced artificially by defoliating the trees just after the harvesting. Luedeling [17] stated that the defoliation of the trees enable them to resume their annual crop cycle without chilling requirements and this type of practice has made the production of temperate fruits possible in countries like India and Kenya. Bud break in case of apple, Japanese plum, apricot, and pear can be broken artificially by a sequence of treatment like desiccating the trees followed by manual defoliation of the tree, renewed irrigation, and rest-breaking treatments [57]. The problems associated with insufficient chilling have also been overcome by adopting the existing cultural technique of defoliation [58]. Chemical defoliation of peach by zinc sulphate and of apple by copper sulphate or urea enhances sprouting of buds. In apple, the defoliation by chemical treatment gave better results as compared to manual defoliation. Late pruning and delayed irrigation strongly influenced bud break in peach in Mexico [59].

**Breaking rest period by chemical application:** Insufficient chilling during winter period usually results in delayed and erratic blooming and foliation of deciduous fruit and nut trees [60]. The rest can be broken under certain conditions by using chemicals such as DNOC oil [61] or cyanamide [62]. Environmental conditions during the rest period are especially important in determining the optimum spray time of rest-breaking agents. Taylorson and Hendricks [63] have shown that many of the rest-breaking chemicals inhibit catalase and allow activation of certain peroxidises. Cutting et al., [64] reported that the use of hydrogen cyanamide and DNOC oil treatments resulted in 3 and 4 weeks earlier bud-break in 'Granny Smith' apple, respectively. Petri [65] treated apple trees with Mineral oil (4-6%) + DNBP (dinitro-butyl-phenol) at 0.13% to 0.2%, and found that Mineral oil at (4%) with DNBP (0.12%) increased lateral bud break rate by 40%. Hydrogen cyanamide (Dormex) at a low concentration (0.5%-1%) in combination with winter oil (3-4%) is now recommended commercially on apples in South African [66]. George et al., [67] found Armobreakand Waikenthe most successful rest-breaking chemicals but only when combined with potassium nitrate which greatly improved their efficacy by 20-30%.

### Future thrust

- Systematic breeding for development of low chill cultivars of temperate fruits to be grown on vast land under low hills and northern plains.
- Better functional models are needed for making robust projections of climate change impacts on the phenology of temperate perennials.
- Environment friendly chemicals for breaking the rest period should be generated.
- Development of new techniques which can manipulate the chilling requirement of temperate fruit crops.
- Adoption of weather-based monitoring strategies for rapid and effective diagnosis of insect, pest and diseases.

## Conclusion

The extent of projected changes in climate in many temperate fruits growing regions indicates that the fulfilment of chilling requirement will likely experience more problems in the near future. These changes are also dependant on how much greenhouse gas mitigation is done to subside temperature increase and climate change. The rate at which global temperature and winter chill accumulation are changing indicate that some aspects of climate are changing much faster than is suggested by the models. The climate change affects not only the winter chilling of fruit crops but it also affects the other aspects like increase in the incidence of physiological disorders, pollination failure and phenology. As global warming is considered inevitable, endeavour should thus be undertaken to manipulate the chilling requirements of the temperate fruit crops by various means, so that the effect of changing climate could be mitigated more efficiently.

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