Effect of Climate Change on Grape and Its Value-Added Products

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Abstract

In India, majority of the grape vineyards are located in semiarid climate. Climate change may aggravate the already serious problems of irrigation water availability and salinity. The elevated CO_2 levels may increase productivity in arid and semiarid regions, but the drought stress caused by higher evaporative demand may override beneficial effects of increased CO_2 in the atmosphere unless irrigation is increased to compensate the evaporative demand. Higher temperature may advance the ripening of berries and alter the berry composition in both table and wine grapes, thereby affecting the quality of the produce. Developing heat-tolerant grape varieties and salt- and drought-tolerant rootstocks, though essential, requires long period. Until new varieties/technologies are developed to improve water use efficiency and cope up with salinity, the emphasis needs to be given on propagation of existing crop production techniques that can mitigate the impact of climate change. There is also likelihood of change in the incidence and pattern of insect pests like mealy bug, thrips and mites. Similarly the disease incidence pattern is also likely to be affected with the change in climate. This is evidenced by decrease in productivity during the recent years from more than 25 t/ha to 8.3 t/ha during the year 2009–2010 and11.7 t/ha during 2010–2011 due to unseasonal rains which lead to serious downy mildew incidence. Changes in cropping season to adjust to changed climate will bring market competition-related issues particularly for Indian table grape industry in domestic as well as global markets.

7.1 Introduction

Grape is one of the most important horticultural crops, growing in 0.11 million ha area with a production of 1.235 million t (Anonymous 2012). Majority of the grape-growing areas are in the semiarid tropics with problems of drought and salinity being important abiotic stresses. The

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productivity which was once more than 25 t/ha in India declined to 8.3 t/ha during 2009–2010 and 11.7 t/ha during 2010–2011 (Anonymous 2011, 2012) due to serious downy mildew disease developed by the unseasonal rains during the critical growth period. According to FAO (2003), production systems in marginal areas with respect to water face increased climatic vulnerability and risk under climate change, due to factors that include, for instance, degradation of land resources through soil erosion, overextraction of groundwater and associated salinization and overgrazing of dry land. More than 90% of simulations predict increased droughts in the subtropics by the end of the twenty-first century (Bates et al. 2008), while increased extremes in precipitation are projected in the major agricultural production areas of southern and eastern Asia, eastern Australia and northern Europe.

Worldwide, grape-growing regions are often classified into so-called Winkler regions according to heat summation measured in cumulative growing degree days (GDD), a scheme originally proposed by Amerine and Winkler (1944). This method sums up the mean daily temperatures above a threshold typically set at 10°C over a 7-month "standard" growing season (April–October in the northern hemisphere and October–April in the southern hemisphere). Each 1°C increment in mean temperature adds 214 GDD to the standard growing season. Therefore, if one assumes an average increase from the present of 1.5°C by 2020, cumulative heat units would increase by 321 GDD. A 2.5°C increase by 2050 would add 535 GDD to the current heat units. This simple estimate shows that the projected rise in temperature associated with global climate change (IPCC 2007) will likely shift several of the world's growing regions into the next higher Winkler region by 2020 and that this shift will affect most regions by 2050. In addition to the predicted temperature rise, the atmospheric CO_2 concentration which is currently ~380 ppm is projected to reach up to 600 ppm by the end of the twenty-first century, which is expected to accelerate the warming trend (IPCC 2007).

Although hot extremes and heat waves are set to become more frequent over the course of this century (IPCC 2007), the most imminent challenges facing the wine, table grape and raisin industries in arid and semiarid regions are probably not heat waves per se but increasing drought and salinity because of higher evaporation coupled with declining water availability (Schultz 2000; Stevens and Walker 2002). The precipitation patterns are changing, perhaps raining at undesirable times, and encouraging excessive vegetation early in the season or fostering fungi and mildew. Warming climates are sure to encourage new pests and diseases, notably insects following their habitat change. They may also affect the natural parasites and predators increasing pest attack due to change in the natural ecosystem. There may be changes in pathogen populations and introduction of new pathogens to new areas (Garrett et al. 2006). Further, seasonal changes in climatic conditions, too, are impacting grape productivity either in terms of reduced fruitfulness due to high temperature, increased disease and pest problems due to unseasonal rainfalls and/or salinity due to reduced rainfall. In fact, the seasonal changes can also influence the formation and ratio (at favourable levels) of sugar and pro-phenols in grapes, thereby affecting the quality of produce.

7.2 Effect of Elevated CO_2 Levels on Water Use Efficiency and Quality of Grapes

Studies carried out earlier on grapevine response to elevated carbon dioxide revealed that doubling the carbon dioxide in the atmosphere results in strong stimulation of yield without having any negative or positive repercussion on grapes at maturity stage (Bindi et al. 1996, 2001; Bindi and Fibbi 2000). Acid and sugar contents were also stimulated by rising CO_2 levels up to a maximum increase in the middle of the ripening season (8–14%); however, as the grapes reached the maturity stage, the CO_2 effect on both quality parameters almost completely disappeared (Bindi et al. 2001). Jose et al. (2006), using elevated CO_2 levels of 365 ± 10 ppm and 500 ppm ± 16 ppm on *Vitis vinifera* L. cv Touriga Franca, found that the net carbon dioxide assimilation rate increased significantly and stomatal conductance reduced in elevated CO_2 leading to improvements in intrinsic water use efficiency, reduction in stomatal density and increase in leaf thickness. However, titratable acidity, tartaric acid, malic acid and wine compounds were not significantly affected. Goncalves et al. (2009) reported from experiment on grapevines grown either in open-top chambers with ambient (365 ± 10 ppm) or elevated (500 ± 16 ppm) CO_2 or in an outside plot, that, in general, the increase of CO_2 did not affect berry characteristics, especially the total anthocyanin and tannin concentrations. However, the total anthocyanin and polyphenol concentrations of the red wine were inhibited under elevated CO_2. They further predicted that rise in CO_2 did not produce negative effects on the quality of grapes and red wine; although some of the compounds were slightly affected, the red wine quality remained almost unaffected.

According to Schultz (2011), one of the biggest "unknowns" and thus challenges in the discussion on sustainability and climate change is related to the lack of knowledge about how plants, microorganisms and pathogens will respond to a rise in CO_2 concentration, temperature and a possible lack of water simultaneously under field conditions. For this challenge to be met, the primary limitation is the establishment of sufficiently large infrastructures to simulate future climate developments such as increased CO_2 concentration and temperature under field conditions. Recent results from models including the physiological impact of CO_2 on plants (more biomass, reduced stomatal conductance) suggest that rising CO_2 will increase the temperature-driven water evaporation from the oceans resulting in an increased absolute water vapour content of the air. However, the decrease in evapotranspiration over land (due to a decrease in stomatal conductance) would still lead to an overall decrease in relative humidity and to an increased evaporative demand according to current knowledge (Boucher et al. 2009). Plant surfaces should then heat up more due to stomatal closure adding to the complexity of expected responses difficult to trace and simulate in conventional experiments (Schultz 2011). Earlier studies by Bindi et al. (2001) showed an increase in the fruit sugar concentration and a reduction in acidity levels under elevated CO_2, but the response of other components contributing to flavour and aroma of grapes was heterogeneous and indicated a significant "chamber effect", with plants grown outside responding differently than plants in open-top chambers with or without elevated CO_2 (Gonçalves et al. 2009).

From the above findings, it appears that grapes in arid regions may, therefore, benefit from increased CO_2 and partly overcome some of the adverse conditions created by drought as reported by Schultz (2000). Furthermore, expected rise in CO_2 concentrations may strongly stimulate grapevine production without causing negative repercussions on quality of grapes and wine. In the absence of environmental stresses, grapevines would perform well under increased atmospheric CO_2. But on the whole-plant level, long-term elevated CO_2 exposure probably may have very different effects. The initial increase in photosynthesis may be partly or completely downregulated if sinks for the photosynthates are not sufficient over a period of time (days, weeks or months of growth) in elevated CO_2, the acclimation response may be substantial enough that the photosynthetic rates of plants grown and measured in elevated CO_2 may even become equal to those grown at current ambient concentrations (Bazzaz 1998). It is difficult to predict the combined action of several changing environmental factors. Faster development of larger leaf areas may have important consequences for water consumption and canopy management.

7.3 Effect of Temperature on Vine Growth and Development

Climatic changes like temperature, sunshine hours and unseasonal rainfall can cause shifts in grapevine growth stages that are observable in terms of phenological events, such as budburst, flowering, veraison, harvest and then in yield as well. These seasonal changes to a greater extent can influence the formation and ratio of sugar and pro-phenols in grapes, thereby affecting the quality of produce. In a study covering 18 years of data collection, the percentage of fruitful buds in Thompson Seedless (TS) correlated highly with air temperature and hours of sunshine during a 20-day period at the beginning of a season (Baldwin 1964). This critical period corresponded to growth stages 13–18 of the modified Eichhorn and Lorenz system (Coombe 1995). When air temperature alone was varied in a growth chamber study (Buttrose 1969), bud fruitfulness of Muscat of Alexandria rose from zero at 20°C to a maximum close to 35°C and was followed by a steep decline beyond 35°C. Varieties differ in tolerance to temperature as is evident from the results of Kadir (2005) who subjected four European (*Vitis vinifera* L.) wine grape cvs., Semillon, Pinot Noir, Chardonnay, and Cabernet Sauvignon, and one American (*Vitis aestivalis* Michx.) wine grape cv. Cynthiana, to three temperature regimes in growth chambers. In general, the best temperature for shoot and root growth 28 days after temperature treatments was 20/15°C for Semillon, Cabernet Sauvignon, and Cynthiana and 30/25°C for Pinot Noir and Chardonnay. Pronounced reduction in number of leaves, shoots, tendrils, internodes, total leaf area (LA) and total shoot biomass was more in cv. Cynthiana than in the European cultivars. This shows that the European cultivars were relatively more tolerant to high temperature than the American cultivar and they have a potential for production of wines in hotter areas. Optimum temperature for photosynthesis in Sultana leaves is estimated between 25°C and 30°C (Kriedemann 1968; Kriedemann and Smart 1971). However, vine leaves can attain temperatures up to 10°C higher than ambient temperatures (Kriedemann and Smart 1971). Shaulis (1966) had suggested that under conditions of higher temperatures (42°C) vines are not capable of utilizing radiant energy possibly because the degradation of enzymes and chlorophyll exceeds rate of photosynthesis (Kliewer 1968).

The annual succession of phenological stages of grapevines is commonly observed to be accelerated with a rise in temperature (Alleweldt et al. 1984; Jones and Davis, 2000; Chuine et al. 2004; Duchêne and Schneider 2005; Wolfe et al. 2005; Webb et al. 2007). Such observations show a consistent trend towards earlier flowering, veraison and harvest. The timing of veraison may be of particular importance, because earlier veraison implies that the critical ripening period shifts towards the hotter part of the season. This has already been described for Alsace, France, where the period between budburst and harvest has become shorter, and ripening is occurring under increasingly warm conditions (Duchêne and Schneider 2005). Because ripening grape berries are designed to minimize transpirational water loss (Radler 1965; Possingham et al. 1967; Blanke et al. 1999; Rogiers et al. 2004), they cannot take advantage of the evaporative cooling mechanism that protects leaves from overheating. Thus, while high temperatures tend to accelerate grape ripening, too much heat can inhibit or even denature berry proteins, and may lead to symptoms of sunburn. Model calculations performed for Australian wine regions also project a forward shift in harvest date, which was arbitrarily defined as grapes reaching soluble solids content of 20°Brix (Webb et al. 2007).

In Baden (southwest Germany), the yearly average temperatures of the last 10 years were 1.2°C higher than the average of 1961–1990 (Sigler 2008). The average dates for the beginning of maturation of Pinot Noir in Baden had advanced by 3 weeks from 1976 to 2006 (Sigler 2008). In the Palatinate (Germany), annual average temperatures increased by 1.2°C from 1970 to 2005 and harvest advanced 2 weeks (Petgen 2007). In coastal California areas, average annual temperature increased by 1.13°C and the start of the growing season advanced 18–24 days between 1951 and 1997 (Nemani et al. 2001). From the above findings it is evident that drought stress caused by higher evaporative demand due to rise in temperature may override beneficial effects of increased CO_2 in the atmosphere unless irrigation can be stepped up to compensate. Moisture stress reduces photosynthetic activity in grapes (Kriede-mann and Smart 1971; Liu et al. 1978). Higher frequency of extreme temperatures in summer will automatically lead to increased evapotranspiration which coupled with reduced precipitation may render full or partial use of cover crops impossible in vineyards. The cover crops compete for moisture with the vines and off-flavour problems in white wine have been linked to competition problems for water and nitrogen between cover crop and grapevines in dry years (Rapp et al. 1993). As per available information, 1 mm increase in pan evaporation will increase the irrigation requirement by 4200 l/ha/day during the vegetative and berry development stage if saline irrigation water is used for irrigation (Sharma et al. 2008) under central Maharashtra conditions. Cooler areas like Nasik may benefit from warm night-time temperatures. Development of salt-tolerant and drought-tolerant rootstocks, heat-tolerant varieties and technologies to deal with the heat and salinity stress is essential, but it is a time-demanding process. Until new varieties/technologies develop, the emphasis is to be given on management of crop production techniques with the available technologies.

7.4 Effect of Ultraviolet Radiation Levels on Grapevine Physiology and Grape Composition

As part of those changes in climate and rise in temperature, there will also be changes in solar radiation and levels of UV-B radiation will probably continue to rise. The impact of UV-B on higher plants includes decrease in leaf expansion (Tevini and Teramura 1989) and reduced fresh and dry weight, total biomass and photosynthetic capacity (Krupa and Jager 1996). The effects of UV-B could accumulate from year to year in long-lived perennial plants such as trees (Madronich et al. 1998), and thus, there is a chance that this may also occur in grapevines.

The effects of solar radiations will have marked effect on berry pigmentation and wine flavour and composition. Flavour development will be affected via alteration of secondary metabolites such as flavonoids, amino acids, terpenoids, alcohols and carotenoids. Some key enzymes involved in flavonoid biosynthesis (chalcone synthase) and the phenyl-propanoid pathway (phenylalanine ammonium-lyase) in many crops have been shown to be unregulated by UV radiation, as are levels of key antioxidants glutathione and ascorbate, whereas carotenoid pigment formation and the incorporation of nitrogen into amino acids (AA) can be inhibited (Dohler et al. 1995; Tevini 1996; Jansen et al. 1998). Since components such as flavonoids, amino acids and carotenoids are important constituents of grapes with a marked effect on flavour development, some influence of UV-B radiation on grape composition can be expected (Schultz et al. 1998). On the molecular level, UV-B can destruct peptides and lipids and can photodegrade the plant hormone auxin which absorbs in the UV-B range and may play a significant role in the formation of an off-flavour in white wines that is increasingly found over the last decade in Central Europe (Gebner et al. 1999).

Solar radiations will have marked effect on berry pigmentation and wine flavour and composition. Rising CO_2 concentration alone may increase grape production and water use efficiency, but more comprehensive studies predict decreases in yield when increasing temperature and changes in solar radiation are considered simultaneously.

Viticulturally relevant consequences may also stem from the effect of UV-B radiation on exposed fungal vine pathogens (Keller et al. 2003), which tend to be more susceptible to UV-B radiation than higher plants (Caldwell et al. 2007), as well as herbivorous insects and disease vectors (Caldwell et al. 2007), either directly or mediated by an altered chemical composition of the vines. Caldwell et al. (2007) reviewed works that described the improvement of frost tolerance from UV-B in several plants. With regards to grape aroma, major effects may stem from changes in the composition of phenolic compounds (Schultz et al. 1998; Lafontaine et al. 2005), which play a significant role as photo-protective pigments in vines (Caldwell et al. 2007), and as antioxidants, colour, aroma and mouthfeel-relevant compounds in wines. Schultz (2000) reviewed some examples of possible UV-B radiation-mediated consequences, but the overall effects of increased UV-B radiation levels remain understudied.

7.5 Carbon Sequestration Potential of Grapevines

Carbon sequestration plays an important role in the global carbon cycle. Carbon sequestration can be defined as the retention of carbon to prevent or delay its release to the atmosphere as CO_2. Plants are considered a "sink" for CO_2 because they uptake this gas during photosynthesis. Because plants assimilate carbon, enhancing their populations helps limit atmospheric concentrations of carbon dioxide. Perennial plants are particularly efficient at carbon sequestration because carbon is stored in permanent structures. Every year on a global scale, a very large amount of carbon dioxide (on the order of 100 billion metric tons) is sequestered. At the same time, carbon is released to the atmosphere from vegetative respiration, combustion of wood as fuel, consumption of biomass for food and natural decay. The net numerical difference or flux between carbon sequestration and release can be viewed as measure of the relative contribution to biomass to the carbon cycle.

The biomass production in Indian vineyards under double-pruning and single-cropping system is estimated to be 4.0–5.0 t/ha/year for leaves and canes and 5.0–6.0 t/ha/year for dry fruit yield. In grapevine orchards producing 4.0 t/ha of dry matter, CO_2 equivalent has been estimated to be 8.0 t/ha (Nendel and Kersenbaum 2004) in New Zealand. Taking these figures into consideration, the CO_2 sequestration in the Indian vineyards under double-pruning system can range from 18 to 22 t/ha/year. These figures do not take into account the carbon stored in the permanent vine parts. Considerable carbon is sequestered in the perennial vine parts like trunk, roots and cordons. Carbon dioxide sequestration in vineyards can further be increased by the use of green manuring and cover crops. Data on net numerical difference or flux between carbon sequestered and released as result of decomposition of pruned material and grapes are not available.

7.6 Indian Viticulture: Where Are We?

Documented information in context of impact of climate change on Indian viticulture is not available. Nevertheless, preliminary information gathered based on field visits, etc. gives indication of possible impact of the climate change on viticulture.

7.6.1 Effect of Climate on Grapevine Phenology, Yield and Quality

In India, majority of the grape-growing areas follow single-cropping and double-pruning system. Cost of cultivation is more in these areas as compared to temperate viticulture, because plants remain active throughout the year and need to be maintained. The delay in sprouting during foundation pruning particularly in late-pruned vineyards (pruning done during and after 4th week of April) results in delayed cane maturity and less number of degree days available for proper bud differentiation particularly if this period coincides with the rainy and/or cloudy weather. High temperature after foundation pruning delays bud sprouting in Thompson Seedless vines grafted on Dogridge rootstock. Vines pruned on 10 April 2008 took 20–25 days for initiation of bud sprouting when temperature ranged from 39.0°C to 41.1°C during the second week after pruning compared to 12–15 days (pruned on 23 April 2008) when the temperature ranged from 35.9°C to 38°C during the second week after the pruning in April (Sharma J and Taware PB, unpublished data). Application of hydrogen cyanamide (bud dormancy-breaking chemical) did not have any effect on promoting early bud sprouting in the vines pruned on 10 April 2008.

Warm night-time temperatures are important for table grape yields, with an optimum average minimum temperature of approximately 17.5°C. Warm night temperatures in December–January may accelerate growth during veraison, which may shorten the lag phase in berry growth and thus allow berries to grow larger with more time spent in active growth. This is particularly important for areas like Nasik, where the night-time temperatures are generally less than 10°C during berry development stage, and the grapes are harvested after about 150 days after flowering. In areas like Sangli and Solapur where night-time temperature are comparatively higher (>10°C), the grapes are ready for harvesting in 130–140 days. Night-time temperature in certain locations like Niphad and Vani drops sometimes below 1°C. Severe frost damage has been observed in some of the vineyards in 2008 and in Dindori and Pimpalgaon areas during the year 2012 leading to severe damage to developing vegetative and cluster tissues thereby resulting in severe crop losses. Rise in night-time temperatures will decrease the risk of frost damage in such areas.

When the day temperature is high, exposure to sunlight during berry development and ripening results in berry discoloration (sunburning) thereby affecting the market acceptability. Berry discoloration due to high temperatures and exposure to sunlight is more severe and common in raisin-producing regions like Sangli, Pandharpur and Solapur where the temperatures are comparatively hotter and climate is drier compared to Nasik region which is comparatively cooler. High diurnal variations and low temperatures have been found to increase the incidence of "pink berry" disorder in white grape varieties like Thompson Seedless and its mutants. Use of shade nets and covering the grape bunches with paper bags have proved an effective tool in minimizing the berry discoloration problem.

7.6.2 Effect of Climate on Grapevine Water Requirement, Nutrition and Soil Quality

Indirect effect of increasing temperature could lead to low water availability and increased salinity if it is coupled with decline in precipitation. The drought stress caused by higher evaporative demand due to rise in temperature may override beneficial effects of increased CO_2 in the atmosphere unless irrigation can be stepped up to compensate the water requirement of the vines. Leaf blackening and degradation of chlorophyll has been observed in recent years as a result of high temperatures (exceeding 30°C) during berry ripening in many grape-growing areas of India. The berry weight is reduced in the vines exhibiting the symptoms. The incidence is more in leaves facing sunlight directly for longer duration. Preliminary studies on green and chlorotic leaves present on the same vine revealed that potassium concentration was reduced greatly in leaves suffering from sunburn and the severity of blackening increases with the moisture stress (Sharma J, unpublished data).

Due to rise in temperature, the evaporation from the soil surface will increase leading to the accumulation of salts on the soil surface. The combination of drought and salinity will affect the nutrient availability to vines adversely. In heavy soils, where drainage is restricted and rainfall is less, use of saline irrigation leads to potassium deficiency and toxicity of sodium and chloride causing leaf blackening and necrosis. This reduces fruitfulness and yield and can even lead to death of perennial vine parts (Sharma et al. 2010, 2011). These symptoms are commonly observed and develop much earlier in hot and drought-prone areas such as Solapur, Sangli and Bijapur where groundwater is saline and rainfall is low compared to Nasik region where temperatures are comparatively mild and total rainfall received is higher. Although grape growers have adopted drip irrigation system, considerable moisture is lost as evaporation from soils having poor infiltration/compaction. These evaporative losses can further increase with rise in temperature under climate change. These evaporation losses can be minimized by subsurface irrigation, use of mulches and reducing transpiration losses with the help of antitranspirants. Application of drip water below surface from the existing surface irrigated drip system resulted in higher water use efficiency (Sharma et al. 2005, 2011). Use of mulches and antitranspirant (antistress) resulted in 25% saving of water when compared to surface drip irrigated vines (Upadhyay et al. 2006).

7.6.3 Effect of Climate Change on Indian Wine Industry

In wine grape there is a possibility of taking two crops in a year cycle to increase total annual yield, without compromising wine quality. Especially white varieties like Sauvignon Blanc and Chenin Blanc, which mature within 110–120 days, can produce two yields in a year. Rise in temperatures during cooler months of the year in our present climatic conditions will help such cropping system due to possibility of reducing the ripening period. However, based on the information generated elsewhere, the rise in temperature will demand more electric supply to maintain the desired temperature during fermentation and storage of wines taking into consideration the present wine-processing season in India. It will require more investment in the wine industry and the production cost will increase. Further, as sugar content is likely to increase with accelerated ripening, climate change will lead to wines with modified sugar/acid ratios unless acid is added back to the must (Duchene et al. 2010). Increased sugar concentrations may cause growth inhibition or lysis in microorganisms. This is turn, may result in sluggish alcoholic fermentations, whose occurrence have been reported to increase drastically in hot years (Coulter et al. 2008), and pose a significant problem to the wine industry. Also, under high temperatures during harvesting, vine metabolism may be inhibited leading to reduced metabolite accumulations, which may affect wine aroma and colour. Musts with high sugar concentrations cause a stress response in yeast, which leads to increased formation of fermentation coproducts, such as acetic acid. If not controlled by acid addition, the higher pH can lead to significant changes in the microbial ecology of musts and wines and increase the risk of spoilage and organoleptic degradation (de Orduna 2010).

To prepare for the future, the wine industry should integrate planning and adaptation strategies to adjust accordingly. To facilitate planning for and adaptation to climate change, focused research is needed in two main fields: production of finer-resolution climate simulations more appropriate for assessing microclimates critical for grape growing and improved viticulture modelling-incorporating treatment of varietal potential, phenological development, and vine management and carbon sequestration. The industry may choose to preserve its current wine styles, based on well-known varieties grown in particular climates, and move to the present cooler regions.

7.6.4 Effect of Climate Change on Disease Incidence and Pattern

Anthracnose, a fungal disease, appears only on tender shoots, while bacterial leaf spots (*Xanthomonas sp.*) are seen on old leaves. Both diseases require warm humid conditions for its rapid development. In Maharashtra, during summer showers (May) or early monsoon showers (June), warm and humid climate is present, but most of the time, leaves are not mature and there are plenty of young shoots present in the vineyards. Under these conditions, high incidence of anthracnose is observed but not of bacterial leaf spots (Sawant and Sawant (2008) Effect of rise in temperature and changing climate on disease incidence pattern (personal communication)). During September–October, relatively hotter grape-growing areas (Hyderabad, Latur, Osmanabad, Solapur) receive rain from north-east monsoon. During this period, leaves are matured and many times near senescence and weather is warm and humid. Under such weather conditions infection of bacterial spots is commonly observed instead of anthracnose. Immediately after forward pruning in October, new shoots emerge and warm and humid climate continues till November. Now instead of bacterial leaf spot, anthracnose is seen on shoots, if it rains.

In the event of hot weather likely to prevail even during August and early November, bacterial spots are likely to increase during this period. Bacterial spots in warmer areas contribute to premature leaf drop before forward pruning. Early appearance of bacterial leaf spot due to warm temperatures will increase the chances of leaf drop. Similarly, if warm temperatures prevail during November, bacterial infection can be seen on inflorescence causing direct yield loss. Unlike fungal diseases, bacterial diseases are difficult to control, as effective chemicals are not available. The bacterial infections in grapes are under control due to present climate and suitable pruning timings. This advantage is likely to be gradually reduced due to warm weather and bacterial infections will become prominent. In above-mentioned grape areas, bacterial infections on pomegranate plants are causing serious problem and as yet do not have effective solution. Grape may face same fate if warm temperature prevails for long duration.

Downy mildew infections can occur in a wide range of temperatures if wet condition prevails. Rains during September–October will lead to downy mildew infection on leaves which will cause leaf drop before forward pruning, while wet conditions after forward pruning can increase downy mildew on young shoots and bunches causing yield loss. Bacterial infection will also be increased due to downy mildew infection. Recently the decline in grape productivity is attributed mainly to the unseasonal rains leading to heavy downy mildew incidence. This has further led to change in pruning time. In fact in some areas, the pruning time has shifted from October to November. But this shift could affect the berry growth as berry setting stage coincides with low temperatures.

There is a practice of early fruit pruning in many areas such as Satana in Nasik district and Bori in Pune district. Early pruning is taken to bring the grapes in market during November and December and to get good price. Such a pruning practice became common due to rain pattern in this area. It is interesting to note that in Satana area fruit pruning is taken from June 15th onwards. During early monsoon months, there are very scanty rains and maximum temperature remains above 30°C for a long time. Due to such high temperatures even if it rains, downy mildew does not develop on new shoots. In vineyards pruned during June–July, downy mildew is not developed or remains within manageable limits. While in vineyards pruned after July, downy mildew management becomes more and more difficult as maximum temperature drops below 30°C as more rains are received. Earlier, it never rained after October, and hence, harvesting during November, in case of above-mentioned vineyards, was very safe. However, during the last 2–3 years, rains during November and December have become regular feature. These rains cause heavy damage to harvestable crops in early pruned vineyards. Direct losses due to hail storms or cracking of berries due to high relative humidity are the major problems in such crops. Even minor rain during November and December period reduces the shelf life of the crop substantially due to post-harvest rots; thus, growers do not get good price.

7.6.5 Effect of Weather Factors on Insect Pest Incidence

The last two decades of grape cultivation in India witnessed sea change in insect pest scenario. Girdler beetle which was major pest in grapes became minor one and minor pests such as thrips, mealy bugs, red spider mites and stem borer became major. Moreover, jassids, scale insects, caterpillars, flea beetle and chafer beetle have potential to become major pests in near future. Outbreaks of red spider mites in Sangli and Solapur districts of Maharashtra during March–April 2011 and jassids in Nashik district of Maharashtra during November 2011 in grapes are the recent examples. This shift in pest scenario may be attributed to change in climate and cultivation practices. Insects and mites are cold-blooded organisms which mean that their body temperatures are approximately the same as that of the surrounding environment. Therefore, temperature is most important environmental factor determining insect life cycle and multiplication. Insect life cycle forecasting studies are calculated using thermal constant. It was estimated that increase of 2°C temperature can result in one to five additional generations per season (Yamamura and Kiritani 1998). The moisture and CO_2 effects on insects may also be important in climate change scenario as estimated by Coviella and Trumble (1999), Hunter (2001) and Hamilton et al. (2005).

Crop-growth-stage- and degree-day-accumulation-based models can be used to predict the development of insects and mites. Increase in temperature within favourable range can increase the rate of development of insects. In case of natural enemies, increase in temperature may lead to reduced parasitism if host populations pass through vulnerable life stages more quickly thus reducing the parasitism period. Temperature may also affect gender ratios of thrips (Lewis 1997) thereby affecting reproduction rates. Increase in temperatures may also lead to lower winter mortality of insects which can finally result in higher population levels (Harrington et al. 2001).

Future strategies for mitigation of effect of climate on insect and mite pest complex include development of automatic decision support system based on weather forecasting with the aim to give advisory to farmers on daily basis through the World Wide Web. Mealy bug population build-up was found to be coincided with increase in temperature, decrease in the humidity and advancement in the berry development. Thrips population was negatively correlated with minimum temperature (r = −0.72) and rainfall (r = −0.43). Results also indicated that the mite population increased from 4.20/leaf in December to 24.20 mites/leaf and it was negatively correlated with minimum temperature (r = −0.48) and relative humidity (r = −0.65) in Pune conditions (Anonymous 2009).

7.7 Mitigation Strategies and Future Researchable Issues

Majority of the grape cultivation in India is concentrated in the agro-ecological region (K4Dd3) with the mean annual precipitation ranging between 600 and 1000 mm, covering about 40% of annual PET demand (1600 and 1800 mm). This results in gross annual deficit of 800–1000 mm of water. Grape-growing regions comprising of districts of Ahmednagar, Beed, Solapur, Sangli (eastern parts), Satara (eastern parts), Osmanabad and Latur in Maharashtra state and Bidar, Gulbarga and Bijapur in Karnataka state constitute drought-prone areas. Severe drought spells repeat once in 3 years. The moisture availability mostly remains as submarginal (Gajbhiye and Mandal 2006). Moisture and temperature stress affects not only the growth and yield of crop but also its quality.

Increased temperature increases the irrigation demand evaporation rate thereby increasing the optimum soil moisture that should be maintained to mitigate the effects of rise in temperature. Own-rooted vines suffer most due to limited root system during drought. To deal with salinity and moisture stress, vines should be raised on rootstocks like Dogridge and 110R. The evaporation losses can be minimized by subsurface irrigation, use of mulches and transpiration losses with the help of antitranspirants. Application of drip water below surface from the existing surface irrigated drip system resulted in higher water use efficiency (Sharma et al. 2005, 2011). Use of mulches and antitranspirant (anti stress) resulted in 25% saving surface drip irrigated vines. Similarly use of mulching and antistress (an acrylic polymer) mulching could result in 25% savings in surface drip irrigated vines (Upadhyay et al. 2006). The existing rootstocks like B-2/56, 110R and 1103P have better sodium exclusion ability than Dogridge and Salt Creek; hence, in areas having sodicity problem, they should be preferred (Anonymous 2009; Sharma et al. 2011).

The architecture of horticulture and crop plants, as well as trees, is influenced by endogenous factors such as hormone signals and trophic competition between organs but also by exogenous factors such as light distribution, temperature, soil water and nutrient regimes. Plant morphology can also be artificially modified by humans through agronomic practices, such as pruning and training (Guo et al. 2011). Canopy management strategies like growing more leaves in hot years to shade fruit, leaf removal on southeast or eastern side of canopy to capture the morning sun, shoot positioning on northwest or western side of canopy to shade fruit in the hot afternoon and managing water to retain differential leaf cover avoid heat stress. Use of shade nets helps in minimizing the heat damage. Shade nets are being used by the growers to minimize the heat injury to vines particularly for grapes grown for export market.

Carbon dioxide sequestration in vineyards can be increased by the use of green manuring, cover crops and incorporation of crop residues. More carbon is likely to be sequestered as a result of increased root biomass under elevated CO_2. However, at present the growers are reluctant to use pruned biomass due to apprehension of increased incidence of downy mildew and insects like borers. Similarly, cover crops and green manure crops will compete with vines under moisture scarcity conditions. However, in areas where irrigation water is not a limitation use of green manuring, cover crops and incorporation of crop residues will be beneficial. Methods to minimize rise in soil temperature, e.g. maintaining optimum soil moisture and mulching, may help in reducing the decomposition rate of the soil organic matter thereby reducing the CO_2 emissions.

Uncertainty of weather is a major factor associated with losses in vineyards. In grape-growing areas, rarely continuous heavy rains are received. Whenever such rains were received, there were heavy losses in vineyards due to diseases and physiological disorders. But in majority of the situations, disturbance due to untimely rains is very less and can be managed if forewarning about the weather disturbances are received and proper guidance on disease management is made available. During the rainy season, especially after fruit pruning, growers tend to spray fungicides excessively. Most of the sprays are followed by rains which results in not only washing off of the fungicides but poor systematicity due to high RH and low transpiration pull. Therefore, in spite of heavy spraying, effective control of downy mildew is not achieved. Managing through preventive sprays well before the rains and following up with sprays after the rainy weather is over can lead to better efficacy of fungicides. However, it is possible only when possibility of rains is forecasted correctly. Recently, technology for location-specific short-term weather forecast is available. National Research Centre for Grapes, Pune, has developed automated online system to generate location-specific weather advisory on a daily basis for management of downy mildew. Such system can be effectively used for management of downy mildew in the event of untimely rains. In many areas, the pruning time has shifted from October to November, thereby leading to better downy mildew management.

7.8 Future Research Needs

- Development of heat-tolerant grape varieties, salt- and drought-tolerant rootstocks and technologies to deal with the heat and salinity stress is essential, but it is a time-demanding process. Until new varieties/technologies are developed, the emphasis is to be given on management of crop production techniques with the available technologies.
- The availability and quality of the irrigation water will be deciding overall impacts of climate change. Research on subsurface method of drip irrigation to determine the depth of application (discharge point) for different rootstocks to further improve the water use efficiency using saline irrigation water is needed.
- There is a need for research on agro-techniques to minimize decomposition of soil organic matter and increasing the carbon sequestration by use of cover crops which do not compete with grapevines for nutrients and moisture and do not increase the disease and insect pest incidence. There is a need for standardization of location-specific and variety-specific agro-techniques.
- Although historical and projected average temperature changes are known to influence global wine quality, the potential future response of wine-producing regions to spatially heterogeneous changes in extreme events is largely unknown. Effect of change in temperature and precipitation on vine growth, berry composition and development and wine quality needs to be studied to modify the vineyard and vinification processes accordingly.
- Studies to establish relationship between temperature and phenology of grapevine and its impact on grapevine productivity are needed.
- Impact of temperature and water stress at molecular level is not well understood. The knowledge of grape genome sequence provides an opportunity to identify the genomic regions imparting tolerance to abiotic stresses. Functional genomics of abiotic stress through whole transcriptome analysis needs to be studied to identify genomic regions involved in stress response.

7.9 Conclusions

Sustenance of today's grape-growing regions will depend on how well we adapt to this situation and mitigate the effects of climate change. The impact of climate change will vary from region to region across the country. A hotter climate would bring variation in quality of both table and wine grapes. In some of the regions, however, the temperature of the ripening period may become too hot to produce balanced wines from some or all grape varieties. Rise in temperature of ripening period in particular is likely to affect berry development and their composition in table grapes also.

Grapes in arid regions may benefit from increased CO_2 and may partly overcome some of the adverse conditions created by drought. Faster development of larger leaf area under elevated CO_2 levels may in turn have important consequences for water consumption and canopy management, which is difficult to predict when several climatic factors are to be considered. However, in the event of environmental stresses like drought, grapevines may not perform well under increased atmospheric CO_2. The elevated CO_2 levels may increase productivity in arid and semiarid regions, but the drought stress caused by higher evaporative demand may override beneficial effects of increased CO_2 in the atmosphere unless irrigation is increased to compensate the evaporative demand. The availability and quality of the irrigation water will decide the overall impacts of climate change. The impact on viticulture would be dramatic, especially in areas like Sangli, Pandharpur, Solapur, some parts of Nasik, Hyderabad and Bijapur where water is a scarce resource.

In view of climate change, varieties have to be replaced and/or the management strategies have to be changed. Development of heat-tolerant grape varieties, salt- and drought-tolerant rootstocks and technologies to deal with the heat and salinity stress is essential, but it is a time-demanding process. Until new varieties/technologies are developed to improve water use efficiency and cope up with salinity, the emphasis has to be given on management of crop production techniques with the available technologies like subsurface irrigation, mulching, use of drought-tolerant rootstocks, antitranspirants, and shade nets. There is likelihood of change in the incidence and pattern of insect pests like mealy bug, thrips and mites. Similarly the disease incidence pattern is also likely to be affected with the change in climate.

There has been a huge historical and cultural identity associated with wine grape-producing regions all over the world. As a result of climate change, a region known for a particular variety, for instance, might need to shift to another kind of grape variety, changing the cultural identity that has developed over centuries. A hotter climate would also change the timing of harvest and ripening. Changes in cropping season to adjust to changed climate will bring market competition-related issues particularly for Indian table grape industry in domestic as well as global markets.

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