Grape cultivation and wine making are backbone for socioeconomic sectors in many European countries. In addition, grape is also being cultivated in many tropical countries like India, Brazil, South Africa, Turkey etc. In viticulture, climate plays a major role in the terroir of a given region as it strongly controls vine microclimate, growth and physiology of vine, yield and berry composition which all together determines wine quality. Since, viticulture deeply depends on weather and climatic conditions, several predictions have been made with respect to climate change where, it is anticipated to exacerbate the distribution of wine growing regions in coming years (Santos et al., 2020). Emission of higher levels of greenhouse gases causes warming of global climate and thereby increases the risk of causing damage to ecosystem. Global mean temperature at the end of 21st century which directly depends on the CO2 concentration which is already been emitted from past centuries. Impact of global warming may alter the regions of grape growing which may result in change of traditional grape varieties to be cultivated (Mozell and Thach, 2014). In United Kingdom, with the increase in average temperature, there are opportunities to extend the wine growing regions in cooler climate with increase in 143% area under wine grapes from 2004 to 2013 (Nesbitt et al., 2016). In contrary, many traditional wine growing regions are negatively affected by warming climate.

With severe heat stress, grapevines may show significantly decreased photosynthetic activity as well as other biochemical processes (Berry and Bjorkman, 1980). During veraison and maturity period, extreme events like heat waves causes significant influence on sugar accumulation which may directly leads to decrease in anthocyanin accumulation (Conde et al., 2016). Secondary metabolites in general and phenolic compounds in particular are primary contributors for color, flavor, aroma, texture, astringency and wine stabilization (Jogaiah, 2013a). High temperature may lead to important losses in these secondary metabolites as they influence in synthesis of volatile compounds which strongly determines wine sensory characters. Thus, extreme weather events like hailstorms, heat waves, frost, high or low precipitation, winds etc. are more likely to occur in the future (IPCC, 2014) which may have potential impact on future viticulture. Thus, there may be significant alteration in the growth of vine and yield, quality attributes, wine style and topocity and hence, it is necessary to adapt suitable strategies to sustain future viticulture and also look for growing grapes in nontraditional regions (Dinis et al., 2018). In spite of having so much varietal and clonal diversity in grapes and their wide variability in adaptation to wide range of climatic conditions, there are several limitations with respect to their suitability and thus there may be a greater threat to maintain future viticulture industry sustained both environmentally and socioeconomically.

**EFFECT OF CLIMATE CHANGE ON WEATHER PARAMETERS AND THEIR INFLUENCE ON VINE GROWTH AND DEVELOPMENT**

Effects of extreme climatic variables which have profound adverse effects on production are drought, high and low temperature, hail storms, frost, oxidative stress, etc.

**Drought**

The limited water conditions during critical stages of crop growth have an impact both in annual and perennial crops. An analysis by (Roy et al., 2012) has shown that the effect of global warming on water availability and its demand will face higher risk of water shortage by mid-century in one third of all countries. More than 400 countries will face risk of extremely high-water shortage. In addition to bringing several physiological, morphological and biochemical changes in plant system, drought can drastically result in the production and productivity of both table and wine grapes. It can also exacerbate other problems where drought can increase the risk of stem borers, mealy bugs, thrips etc. Also, vertebrate damage (mostly monkeys, squirrels, bats etc.) to standing crops in vineyards has been reported.

**Flooding**

In recent years several unseasonal heavy rains is being witnessed in many parts of the country. This unseasonal rain has caused flooding in standing crops which destroys entire vineyards and brings about huge loss to the growers. This unseasonal rains and flooding are becoming quite common every year. Flooding causes several effects on plant
anatomy, physiology and biochemistry. Flooding can severely damage the roots and reduce the fruit yield. Soils may become too compact and there may be loss of soil through soil erosion during heavy rains. Formation of soil crust is also one of the effects of flooding which will have adverse impact on crop growth during following years.

**Heat waves and extreme temperature**

Most of the nations have experienced summer heat waves which are a major challenge to grape growers wherein several physiological stresses on vines, early ripening of berries and berry cracking, increased insects and diseases, has been reported. Prolonged and hotter summer months may increase incidence of insects and mite population; increased weed growth by virtue of long season but also by accelerated pest reproduction. The heat wave may have a significant effect on organic grape growers as their choice of using fungicides and bactericides are much limited. Vine growth and development mainly depends on mean temperature and photoperiod requirement in a given period of time (Nigam et al., 1998). With increase in global temperature, most of the crops will be grown in warmer climatic conditions and have a longer growing season (Rosenzweig et al., 2007). With every increase in temperature by 1-2°C, there may be a negative impact on growth and yield mostly at lower altitudes and a slight positive effect at higher altitudes (Challinor et al., 2008). High temperature has adverse effects on pollination in most of the crops due to damage to plant reproductive parts like stigma and stamen. The temperature prevailing locally has an effect on behavior of pollinators thus varying the number of visits by a single flower thus affecting pollination. On the other hand, changes in temperature during entire season may change the abundance and diversity of pollinators. Higher day temperature can reduce the color hue due to either reduced synthesis or breakdown of anthocyanins (Jogaiah et al., 2013b). Occurrences of several physiological disorders are common due to temperature variation like pink berry formation in Thompson Seedless grapes, berry scorching, sun scald etc. Though higher temperature favors better fruit quality parameters, prolonged excessive temperature may deteriorate fruit quality. Low temperature in fruit crops may reduce bud fruitfulness in grapes, apple, pear, etc. Specific chilling requirements in pome fruits and stone fruits will be affected significantly. There may be earlier dormancy breaking. Kumar and Kumar (2007) have reported adverse effects of low temperature on bud break, reduced flower bud differentiation, reduced pollination etc.

**Unseasonal rains and hail storm**

In recent years under the context of climate change, recurrent pre-monsoon showers are causing havoc to grapes. Rain during flowering washes away the pollen grain resulting in fruit set. In the changing climatic scenario, a major portion of the harvest may be wiped out by storms during later fruit development stage. Changes in rainfall patterns can adversely affect the quality and appearance of fruits. Unseasonal rains encourage pests, which also lower fruit yield. In addition to pre-monsoon summer showers, hailstorm is becoming quite recurring in past few years which are significantly causing losses to fruit growers. Hail can damage all parts of the vines. The hail can break or damage shoots and wounds on scaffold branches and damage fruits and fruits may knock to the ground. Hail damage can severely affect the health of vines in next season which was witnessed in grape vines where, severely damaged vines did not sprout after pruning during next season. Sensitive leaves of the plants become shredded, or ripped by hail. The damage caused by hail leaves scar on the vines which occurs on upper side of the branches and on trunks which are directly exposed to storm. Those vines take very long time to recover from such damages and they also increase the vulnerability of such vines to decay by fungi and attack by insects. After a hard hail, one should know how to care for hail damaged plants and making efforts to restore them to production.

**Elevated CO₂ concentration**

The immediate effect of climate change may be raising CO₂ concentration in the atmosphere. At present, atmospheric CO₂ limits capability of photosynthesis in many fruit crops, among them C3 plants shows greatest potential for elevated CO₂ (Allen, 1994). Rubisco and high temperature play key role in photosynthesis of C3 plants. Because both temperature and CO₂ have interactive effect as there is inverse relation between increased temperature and activity of RuBisCO which may decrease both specificity for CO₂ and solubility of CO₂ relative to O₂ which may result in increased photo-respiratory losses with increased temperature. On contrary, doubling of atmospheric CO₂ and the corresponding decrease in the activity of Rubisco oxygenase reaction might partially nullify the adverse effects of increased global temperature on photosynthesis in C3 plants (Long, 1991). Thus, elevated CO₂ can compensate for the ill effects of high temperature relative to the net photosynthetic rate.

**EFFECT OF CLIMATE CHANGE ON GROWTH, PHYSIOLOGY AND YIELD OF GRAPES**

Climatic conditions are very essential for the growth and development of vines by effective utilization of temperature, water, radiation intensity
Grape Insight

Vineyard management for climate change

thereby not compromising growth, yield and quality (Dinis et al., 2015). Several physiological processes required for overall growth and development are photosynthesis, respiration, water conductivity, osmotic adjustment etc. which may be affected by adverse climatic conditions. But, the early inhibition of growth takes place much before inhibition of photosynthesis and respiration (Zhou et al., 2007). Imbalance in vegetative and reproductive growth of plants may be influenced by increased sunlight penetration deep into the canopy thereby causing impact on the proportion of older and younger leaves during the veraison stage (Wahid et al., 2007). This disproportion may affect yield and quality of grapes at harvest with respect to sugar, acid and secondary metabolites viz., phenolic compounds, tannins, aromatic compounds etc. Phenology is considered one of the key biological marker of stress which can be used to quantify the magnitude of climate change impact in vines during several phenological events (bud break, rapid shoot growth, flowering, berry growth, veraison and at harvest (Garcia de Cortazar-Atauri et al., 2017). Many of the studies have been conducted to see the effect of different climatic conditions through phenology evolution models and they indicated that, many of the grapevine phenological stages will be advanced in the forthcoming years especially fruit ripening and harvesting (Garcia de Cortazar-Atauri et al., 2017). It was clearly established that enhanced mean temperature drastically reduces the number of flowers per panicle (Keller et al., 2010). They also suggested that continuous increase in temperature may result in peculiar development pattern of vines resulting in early flowering and berry softening. This early season crop may lean towards the warmest period of season thus affecting grape yield and quality measured in terms of sugars, organic acids, phenolic compounds etc. Many studies from past decade have clearly demonstrated adverse effect of increasing summer stress on reduced grape yield and quality (Pratt, 1971; Watt et al., 2008; Duchene, 2016). The reduced yield has been attributed to reduced photosynthesis which favors fully ripening of only a few berries (Zulini et al., 2007). Apart from impairment of carbon metabolism, drought can also influence nitrogen metabolism and photosynthesis through reduced activity of nitrate reductase (Bertamini et al., 2006).

VINEYARD MANAGEMENT TOOLS IN CONTEXT OF CLIMATE CHANGE

The above factors which may adversely affect vineyard performance as needs to be managed by different management practices to maintain optimum vine growth and productivity even under adverse situation. Hence, it is highly essential to develop vineyard management tools, adapted to match specific region / variety- rootstock combinations, in order to maximize grapevine quality in a changing climate. Some of the management practices are:

Selection of rootstocks

It is inevitable to use rootstocks for overcoming adverse effects of climate change especially drought, salinity, flooding, high temperature etc. Most of the rootstocks are wild relatives or species of a particular crop which originated in harsh climatic conditions. Sometimes it happens that the local demand for the particular variety or cultivar is very high but due to adverse climatic conditions the potential of that variety cannot be exploited. In such situations, use of rootstock is a way to sustain the production of such varieties. Since, rootstocks have a deeper root system (for drought tolerance), selective nutrient absorption mechanism (for salt tolerance), induce early or late precocity (for heat or low temperature stress) they can be used for grafting on such commercial varieties to overcome the stress situations accordingly. The rootstock, Dogridge followed by Salt Creek showed least mortality at 8 ds m⁻³, salinity (Yohannes, 2006). The cv. Thompson Seedless, which is grown extensively in India for both domestic consumption and export, when grafted on 110R (Vitis berlandieri x Vitis rupestris) rootstock showed lower accumulation of sodium ions and sustained the yield over a period of time (Satisha et al., 2010; Sharma and Upadhyay, 2008). It is also reported that the Thompson Seedless vines, on rootstock 110R, exhibited not only early and uniform sprouting but also increased fruitfulness under 1.8 ds m⁻³ saline water irrigation (Jogaiah et al., 2013a). Rootstock Dogridge performed well under 14 days moisture stress cycle by maintaining high RWC, specific leaf weight, producing excess quantity of proline, ABA which was well correlated with relative high root to shoot length ratio and high root to shoot dry matter ratio (Satisha et al., 2006, 2007).

Weather based forecasting systems

With the impact of change in climate throughout the world, most of the agricultural crops including fruit crops are being severely affected either in-terms of reduced biomass, incidence of more pests and diseases etc. Predicting the yield as per the prevailing climate conditions well in advance may help in taking appropriate measures both by policy makers and farmers either for marketing or storage of excess produce. Such predictions can be achieved through developing forecasting models. Veenadhari et al. (2014) developed a software namely Crop Advisor which predicts the influence of climatic parameters on crop yield. In addition to bring adverse effects on
production and productivity of fruit crops, several major pests and diseases can bring about considerable damage to fruit crops. Some of the common newly emerged pests and diseases which take upper hand with changing climate are borers, mites, mealybugs, thrips, powdery and downy mildew, rust etc. To predict the occurrence of these pests and diseases, weather information is very crucial to develop pest models and decision tools which are helpful in managing these pests. Weather based pest forecasting is very important for efficient use of pesticides, the overall protection of high revenue crops, crop productivity and return to the farmers. The forecasting system may help in implementation of long-term integrated management practices. Use of advanced gadgets in modern world like mobile phones, e mails etc have become effective means for immediately communicating risk of pests to farmers, while still advances in science and technology are making better output from innovative models like high resolution weather research and forecasting available for practical use on the farm (Rabi u et al., 2013). Downy mildew in grapes is a most devastating disease in most of the grape growing countries of the world. It is controlled by repetitive spray of fungicides which may cause severe pesticide residue in harvested and processed products. Reducing the number of sprays is a major issue from both environmental and health of public view points. Based on the 9 years of prevailed climatic conditions, Chen et al. (2020) developed several linear models and machine learning algorithms predicting the probability and severity of disease. The accuracy of the models revealed that onset of the disease has a greater influence on the accuracy of forecasts than weather inputs and, among weather inputs; precipitation had a greater influence than temperature. They selected the best performing algorithm and evaluated the impact of contrasted climate scenarios on risk levels and reported that risk of the diseases at bunch closure decreases with reduced rainfall and increased temperatures in April-May. The model also resulted in reducing the pesticide spray by 50% to control the disease incidence.

Use of bio-inoculants to sustain the production under abiotic stresses

Sustaining the production under changing climate conditions especially high temperature, salinity, drought etc. is possible by some of the eco-friendly measures which may also improve the soil health. Growth promotion through inoculation of some microorganisms like algae or other plant extracts has been reported by several workers which also alleviates the stress in may crop plants. These bioinoculants and bio-compounds like algal extracts, protein hydrolysates, humic acids and fulvic acids and other mixtures not only provide nutritional support to plant growth but also increases stress tolerance. Some non-pathogenic bacteria are found to colonize on plant roots and improve the positive effects of rhizosphere (Van-Oosten et al., 2017).

Plant growth promoting bacteria strains can assist plants by providing an additional supply of an auxin (IAA) and induce salt stress tolerance by reducing stress ethylene levels through the production of 1-aminocyclopropane-1-carboxylate (ACC) deaminase, which might improve root growth and nutrient uptake. Plan growth promoting bacteria (PGPB) can mediate plant growth by different direct and indirect mechanisms viz., increased availability of nutrients, protection to plants from diseases and pests. Mancuso et al. (2006) applied marine bioactive substances (isopropanol extracts from micro algae) to grape plants which enhanced leaf water potential and stomatal conductance during soil moisture stress. In additions, K+ and Ca2+ fluxes at the stomatal level were higher in treated plants than control.

New irrigation methods

Though climate change brings about changes in rainfall pattern, increase or decrease of temperature, emergence of pests and diseases, deficit of irrigation water may be the persistence problem in one or the other region due to scanty rainfall or unequal distribution of rainfall for crop growth. As water is the most precious resource for irrigation, it is to be utilized more carefully to conserve the water for future generations. However, with the changing climatic conditions and reduced rainfall in some regions coupled with reduced water table, there is scarcity of water even to irrigate through drip irrigation. In this direction many novel methods of irrigation are being practiced in most of the tropical and subtropical grape growing regions. Subsurface irrigation, regulated deficit irrigation, partial root zone drying etc. are the new techniques which can improve the water use efficiency without affecting the productivity of crops. Subsurface irrigation systems are known to reduce the water requirement as small amount of water is directly applied to plant root zone where the water is needed thus ensuring sufficient moisture in feeder root zone. The potential benefits of this method of irrigation included improved yield and quality of fruits in addition to reducing the cost of production (Alguacil et al., 2009). In grapes cultivar Thompson Seedless, sub-surface irrigation at four inches depth gave higher yield (12.49 t/ha) than the surface drip irrigation (8.16 t/ha) with water use efficiency of 28.91 kg grapes/mm and 18.88 kg grapes/mm irrigation for sub-surface and surface drip irrigation, respectively. Regulated deficit irrigation (RDI) is new method of irrigation strategy developed in Australia for many crops like grapes, peach, pear, papaya etc. This method of irrigation
considers both the phenology of crops and its capacity to resist water stress conditions. RDI involves applying water in quantities below those necessary to satisfy evapo-transpiration coefficient during certain period of crop cycle when production and crop quality are minimally affected. RDI is normally applied during stages of the crop cycle when reproductive growth slows down and when the vegetative growth and other plant processes may be affected, such effects finally result in improved quality of fruits. Partial root drying (PRD) is another novel method of irrigation where half of the root system is well watered for certain period, while other half is allowed dry. But, this cycle of wetting and drying of partial roots will be altered frequently during crop growth stage (Dry and Loveys, 1998). The principle behind this method of irrigation is when part of the root system is dried, there will be triggering of root to shoot signals, which are transported via xylem vessel to upper part of the plants particularly leaves, where it causes partial closure of stomata which reduces loss of water without affecting photosynthesis process, thus increasing transpiration efficiency.

Use of chemicals under moisture stress conditions

Exogenous application of some antitranspirant compounds viz., phytohormones (ABA, salicylic acid, jasmonic acid), osmoprotectants (proline, glycine betaine), mineral elements (silicon, selenium), clay compounds (kaolinite) may help in alleviating the damage caused by high temperature (Wahid et al., 2007). Some of the other osmoprotectants like polyamines (spermine, spermidine) and quaternary ammonium compounds like glycine betaine improve the stomatal conductance, photosynthetic rate and accumulation of proline in plants.

Meng et al. (2018) reported that application of melatonin before harvest may benefit increased activity of polyphenols and antioxidants in Merlot grapes. However, Bottcher et al. (2013) opined that application of compounds which release ethylene may stimulate biosynthesis of auxins thus assist in development of late ripening strategies. The enhancement of secondary metabolites in grape berries by manipulation of cultural operations may help in overcoming some abiotic stresses due to global warming. Some of the other treatments viz., humic acids and polyamines can increase the pigments in both berries and leaves (Mirdedeghan and Rahimi, 2016). Thus, many studies have been conducted to identify environmentally friendly products like kaoline compounds to maintain yield and quality in challenging climate through their effect on reduction in leaf and berry temperature thereby increasing antioxidant mechanisms (Glenn, 2012; Dinis et al., 2015).

Soil and water salinity management

Several cultural operations can be used as strategies to cope up with changing climatic conditions especially extreme water deficit coupled with salinity, flooding etc. During heavy rainy days, excess runoff can be prevented by allowing the water to penetrate into the soil and recharging the ground water is the long-term strategy to cope up with water limitation during critical stages of crop growth. Increasing the soil organic matter with incorporation of organic residues, on-farm water recycling, growing green manure crops etc. can improve the water holding capacity of soil. Construction of farm ponds, contouring etc. can also reduce the runoff and increasing the water availability to crops. Exogenous application of antitranspirants can reduce the transpiration and use of organic or inorganic mulch can reduce the surface evaporation and this conserve moisture. Some growth regulators help to maintain water balance and chlorophyll content during abiotic stresses like drought and salinity.

The extremes of heat waves may become more recurrent over the course of years in the grape growing regions of the arid and semi-arid climate, drought and salinity may also add to it because of higher evaporation coupled with declining water availability (Schultz, 2000). The increased salinization could pose a serious threat to viticulture, as most of the irrigated vineyards will be at risk from salinization owing to dissolved salts in irrigation water. Under such circumstances, some of the mitigation practices would be flooding the vineyards after harvest of the crop (if plenty of water is available), use of organic / inorganic mulch to reduce soil evaporation, zero or minimum tillage to reduce soil erosion. Use of resistant rootstocks which are tolerant to salinity viz., 110R, 140 Ru, 101-14 Mgt, 1103 P etc. is also one of the strategies to mitigate the adverse effects over a long run.

Precision viticulture

The main focus of precision viticulture is to analyze the variability of vine growth within a vineyard. This approach has witnessed significant limitations since it directly or indirectly considers part of the factors which determines vineyard yield and harvest quality. This is more pronounced in semi-arid and arid regions where water availability is crucial for both yield and quality. Hence, thermal imaging by remote sensing can be a useful tool to estimate variability in water status across vineyard as it allows determining canopy temperature which directly determines transpiration and ultimately plant water status (Santesteban et al., 2016). The information obtained from thermal images was used to calculate the crop water stress index using temperatures measured in leaves. The comparison of crop water
stress index with water potential and stomatal conductance revealed that thermal images were suitable for determining the plant water status and accordingly irrigation could be planned.

Many of the precision viticulture tools can integrate the advanced techniques like artificial intelligence, sensors, decision support system etc. and research outcomes of field and laboratory studies to enhance the production efficiency and profitability by minimizing adverse effects of global warming (Rey-Camares et al., 2015). Acquisition of spectral data from either satellites or remote sensing may be one of the tools in precision viticulture to assess spatial and temporal changes in the soil and plant moisture, vine canopy growth, water status, chlorophyll content, pigments and berry quality parameters (Lamb et al., 2008; Zarco-Tejada et al., 2013). Considering these, integration of high throughput information and the evolving site specific viticultural management can develop a right computer based model, thus permitting the characterization of spatial – temporal variability in vineyards with less effect on vine growth and development (Hall et al., 2002).

**CANOPY MANAGEMENT PRACTICES-SPECIAL REFERENCE TO CHANGING CLIMATIC SCENARIO**

The effect of climate change has already been witnessed across the globe is also true in context of Indian viticulture. Indian viticulture is facing several challenges from past few years and will become more pronounced in coming years which includes changing rainfall pattern, extreme high and low temperature, unseasonal rains, severe incidence of foliar diseases etc. Grape originated in temperate climate, over the years it has been well acclimatized to grow in all the climates of India which includes northern temperate climate, central hot and dry region, southern mild tropical climate etc. In these three regions grape is being cultivated by following three different patterns like single pruning-single cropping, double pruning-single cropping and double pruning–double cropping respectively. As the major area under grape cultivation in concentrated in the central and peninsular region of India consisting of Maharashtra and Karnataka, there is a severe threat to grape industry from past few years due to the above mentioned abnormal climatic conditions. Hence, several canopy management strategies should be planned or adapted in coming years to sustain the grape production in this region.

The main aim of canopy management is to enhance photosynthetic efficiency, uniform canopy spread with accurate distribution of canes having similar vigor, health and good quality grapes having similar sized bunches and berries which will attain uniform ripeness. Canopy management should not only focus on yield and quality components but also the good growth and development of other canopy components which should not get impaired in long run. A well-defined canopy with uniform distribution largely depends on shoot density and thus canopy management begins immediately after pruning right from bud burst till harvest. Abnormal temperature during bud burst period may result in either erratic bud burst or excess sprouting both may result in either suboptimal or supra optimal shoot density. If excess shoots are emerged, shoot thinning is one of the important canopy management practices to maintain canopy balance. Infertile and/or excessive shoots that contribute to non-uniformity of growth and shade in the canopy should therefore be removed during this period. This comprises a judicious removal of infertile shoots not located on canes at approximately 30 cm shoot length. This practice restricts the use of reserve nutrients after bud burst and ensures bud fertility through a well-exposed canopy. The next important canopy management practice is shoot positioning or shoot orientation. With the increase in the temperature and light intensity owing to global warming the bunches which will be directly exposed to sunlight coupled with warm temperature may often display poor quality parameters especially sugar, acids, phenolic compounds and skin color measured as anthocyanins. To achieve good quality parameters, it is necessary to orient the shoots to cover the directly exposed bunches so that only diffused sunlight falls on such bunches. Similarly, berries develop in excess shaded regions may of inferior quality with respect to sugar accumulation, color development and berry size. Here also shoot positioning or orientation is important to expose the clusters to sunlight. As leaves are the major source for photosynthates, it is necessary to maintain proper leaf to fruit ratio to properly apportion the optimum photosynthates to sink organs. Again, depending on the vigor of the shoot with in a variety or across the variety leaf removal also plays a key role in determining the yield and quality of grapes. Excess number of leaves on a shoot may create shades to developing clusters and shaded leaves may increase the incidence of foliar diseases like downy mildew and anthracnose due to buildup of congenial microclimate for disease development. Hence, balanced leaf removal is one of the important canopy management practices in the changing climatic scenario to improve the overall yield and quality of grapes (Jogaiah et al., 2013b).

**Vineyard Design and canopy architecture management**

To increase drought tolerance and to reduce competition between the vines, low planting density might be one of the strategies. Pieri et al. (2012) developed a water balance model and opined that
potential low-density system as on adaptation to future water scarcity. Among two densities studied, reduced planting density allowed grapevine water status to be maintained with moderate limits even under future climatic conditions. Change of row orientation may one of the practices to be followed to cope up with future climate change. Hunter et al. (2016) in their studies reported lower water status for east – west orientation. Similarly, Galbreath (2014) reported limited canopy temperature may increase in east west row orientation. Thus, it was concluded that row orientation along with provision for drainage terraces could reduce water runoff thus following better water infiltration and reduced soil erosion. Training system is one of the components which can determine the percent light interception and exposure of clusters to sun thereby favoring berry ripening after attaining physiological maturity. But, depending on the topography, prevailing climatic conditions one should adopt an efficient training system to favor vine microclimate by lowering leaf to air vapor pressure deficit under moisture stress conditions.

With the increase in temperature and light intensity in future years, the training systems which provide shade to the vines may be suitable under arid tropical climate. Even it is not possible to provide proper shading in a given training system, providing overhead shades seems to be one of the canopy management practices to reduce heat and moister stress rather than providing shades only to the bunches, soil or a partial shade to the canopy (Caravilho et al., 2016). But the studies need to be intensified to see the relationship between timing and duration of shading, whole canopy v/s partial shading, mechanization aspects in shaded vineyards etc (Palliotti et al., 2014). In temperate viticulture, leaf removal after veraison is adopted as one of the measures to reduce rate of sugar accumulation and prolonging harvest date without compromising yield (Poni et al., 2018). However, same may not be applicable in semiarid and arid tropical climate.

**Canopy designing/trellises**

Severe sun scorching to the berries in the exposed region leads to berry shriveling. The proposed increase in temperature in the future scenario of global warming may further worsen the case of shriveling due to excess UV light intensity (Spayd et al., 2002). To overcome the problem changing the vineyard row orientation, use of suitable trellises design and training methods may be one of the options to overcome such problems. In vineyards prone for excess sun scorching, one may adopt sprawl system of training which is cheaper as it can support permanent cordon (Keller, 2010). Due to excess sun burn shoot positioning and leaf removal may be avoided to reduce labor costs. Canopy microclimate may be improved by growing cover crops as they provide cooling effect and reduce ill effects of sun scorch (Nazrala, 2007). Use of overhead sprinkler during berry ripening under a severely hot season can reduce soil temperature and limit the daily thermal amplitudes in the root zone (Pradel and Pieri, 2000). But, following such operations may increase the overall cost of the vineyard establishment.

**LONG AND SHORT TERM STRATEGIES TO OVERCOME ILL EFFECTS OF CLIMATE CHANGE**

Many grape growers pose lot of uncertainty over future climate trends which are very essential to implement practical and scientific approach to enhance adaptation of vines response to such stresses. Hence, strategies should be developed to sustain yield and quality. With increasing temperature, early ripening may happen and hence have to delay the growth cycle by adjusting pruning practices (Bernardo et al., 2017). Some of the adaptive strategies may be of short term or some may be of long term (Van Leeuwen and DestracIrvine, 2017). The short-term adaptive strategies may aim at optimizing grape vine growth and development while long term strategies may aim to take suitable management practices before critical threshold levels of some climatic parameters are reached (Fraga et al., 2012).

Long term strategies include both site specific planting choices which permits increase in the viticultural area under particular climate. The two important long-term strategies are selection of site for grape growing based on the average climatic conditions prevailing over the years and selection of specific variety and / or rootstock which are found to be climate resilient. Vineyard layout, row orientation, training method are some of the basic farm management strategies viz., go for table grapes, raisin grapes, wine grapes etc are also to be considered as long-term strategies. Many reviewers have opined that global warming and water deficit alter the balance of berry sensory attributes through accelerated ripening and death of mesocarp cells (Bonada et al., 2013). These symptoms are noticed in the region where vineyards are grown under not irrigated hilly sides, sandy soils with less organic matter, high density vineyards etc (Williams, 2001). Based on the long-term average, site selection for new vineyard establishment may be in areas which were traditionally considered as marginal with less heat unit accumulation which are now becoming more suitable for grape cultivation. So, establishment of new vineyards should be considered only after analyzing the last 20 years climatic conditions prevailed in those areas. (Moriondo et al., 2013). Selection of ideal varieties should not only depend on their heat unit requirement but their effective
utilization of natural resources like sunlight, water, temperature etc. Hence, the study of adaptability of varieties to combined stresses and identifying resistant varieties with high heat tolerance, water use efficiency etc. will help in choosing variety for long term cultivation in a region (Smart and Coombe, 1983). Many studies have been carried out on wine grapes than table grapes where Jones (1980) classified varieties as "drought avoidance (pessimist)” where they adopt for maximum preservation of water status and very conservatively, they use water in future and other group as "drought tolerance (optimist)” varieties which luxuriously use available water through less regulation of stomatal control. Some major promising pessimist varieties are Grenache, Viognier, Tempranillo, Monte Pulciano etc (Vandeleur et al., 2009; Rogiers et al., 2009; Tombesi et al., 2014); while Shiraz, Chardonnay, Semillon, Sangiovese etc. are classified as optimists (Schultz, 2003; Palliotti et al., 2009). Some of the recent findings have shown that optimist varieties perform better than pessimist varieties as the farmer ones can exhibit higher stomatal conductance and water use efficiency regardless of leaf water potential (Palliotti et al., 2014). Rootstock selection is one of the best criteria for overcoming some of the adverse effects of global warming especially moisture and salinity stresses. Selecting those rootstocks which exhibit moderate to high vigor and can able to increase the yield and slow berry ripening is ideal as 110 Richter, 140 Ruggeri, 779 and 1103 Paulsen (Morando, 2001).

Some of the short-term strategies include the flexible management practices that allow vine productivity to be adjusted to specific local climatic conditions. Similarly, it may include water management techniques, soil management, nutrient management and finally harvest and post-harvest management (Naulleau et al., 2021) which have been discussed in the earlier sections. Though it seems to be distinct classification, sometimes combination of both long- and short-term strategies can sustain grape production under changing climate scenario.

In spite of lot of short- and long-term measures with respect to canopy management strategies developed Keller (2010) opined that interdisciplinary and applied research should be targeted to fully understand the mechanisms by which they will protect vines at extreme climatic conditions.

FUTURE RESEARCH STRATEGIES TO COPE UP WITH GLOBAL WARMING FOR ASSESSING BERRY GROWTH, DEVELOPMENT AND QUALITY ASSESSMENT

At field level

Stress induces several physiological changes in grapevine which may be an alarming signal for grape growers for protecting their crop by adapting suitable strategies. Wilting and yellowing of leaves may be the symptom of several abiotic stresses. Hence, it is necessary to monitor morphological changes at every phenological stage to analyze the growth and development which may help in analyzing the vine’s resilience to changing climate. Some of the non destructive tools to accurately evaluate the physiological state of the plants are photosynthetic efficiency, water status of the plant etc. But, variation in climatic conditions may hinder this field measurement as it may not give actual happenings in vine system (Sebastian et al., 2016). Hence, stable experiments should be conducted at a particular time of the day on a clear sunny day (forenoon) as clouds and rains may not give actual values of photosynthesis. Infra-Red Gas Analyzer (IRGA) can be used to measure gas exchange parameters viz, rate of photosynthesis, transpiration rate, stomatal conductance and Photosynthetic Photon Flux Density (PPFD). Similarly, fluorescence-based parameters may be a tool to assess vines tolerance to a given stress. Vine water status can be measured using a pressure chamber apparatus which integrates both soil and climatic conditions for measuring water potential (Scholander et al., 1964). It will give predawn leaf water potential, stem water potential (Chone et al., 2001). Leaf chlorophyll content tells about the plant’s physiological status and senescence. It also gives indirect estimation of plant nutrient status viz., nitrogen, magnesium etc.

At laboratory level

Some of the laboratory analysis may support the observations recorded at field level. Some of these parameters include pigments, phenols, starch, proteins, lipid peroxidation, plant hormones etc (Lazo-Javalera et al., 2015). Abiotic stresses trigger synthesis of some of plant hormones. These signals regulate specific physiological processes viz., stomatal closure. Thus, quantification of hormones can provide valuable information about hormonal crosstalk and stress responses (Sah et al., 2016). Estimation of heat shock proteins also provides responses of plants to high temperature stress. Similarly, estimation of enzymatic antioxidants, osmolytes etc provides an overview on the plants defense mechanisms. Some of the molecular analysis viz., expression of transcription factors, genes, molecular markers can also seems to be ideal to know in a robust and clear ways the regulation of plant stress responses (Cramer et al., 2011).

CONCLUSION

There is no exception for the effect of climate changes on grape growing as many studies have indicated the adverse effects on agriculture
particularly with respect to increased frequency of extreme events during summer, heat waves and erratic rainfall patterns. Looking over the changes in the climatic conditions over the past two decades, further change may shift in grape growing regions where it will be not easier to achieve desired quality parameters even with most popular variety of that region. The impact of climate change can be observed on both grape physiology and biochemistry. Hence, necessary adaptation strategies should be kept in mind to maintain grape yield and quality parameters. Hence, proper analysis of the climate, selection of climate resilient varieties and rootstocks, vineyard soil and water management practices, advanced canopy management techniques to be made before venture into grape cultivation business. It is essential to integrate efforts on the description of standard methods, data customizing and data management tools beside enhancement in selection of better cultivars and clones through multidisciplinary research which will define our readiness to adapt to climate change. In addition to evolving new cultivars and clones, it is essential to enhance the knowledge about the mechanisms for adaptation of local varieties to local conditions of water stress, radiation, high temperature, vapor pressure deficit etc. so that suitable management strategies can be derived to meet the market demand of popularly grown local varieties. In general, irrespective of viticulture, as far as possible, the risks associated with climate change should be reduced and managed so that sustainable development, economic and social well-being, and effective natural resource and biodiversity conservation can be achieved.

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Received: 05 January 2023 / Accepted: 10 January 2023 / Online: 18 January 2023